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16. ABSTRACT

The Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center at the University of California-Davis, in conjunction with Caltrans Division of Research, Innovation and System Information (DRISI), identified advanced snowplow driver assistance system (DAS) technology that can significantly enhance the safety and efficiency of snow removal operations in certain parts of Interstate 80 in the Sierra mountains in northern California. The DAS was previously developed at the University of Minnesota and used by the Alaska Department of Transportation (DOT). This research evaluated the DAS as implemented for California operations and provided technical support for DAS implementation. The research included collaboration with the University of Minnesota and MTS System Corporation to instrument two snowplows and one snow blower with DAS to support scientific testing and evaluation.

A Global Navigation Satellite System (GNSS) base station was established at Kingvale maintenance station in support of the DAS operation. The DAS GNSS receivers' performance was evaluated. The DAS radar unit experienced icing during heavy snow storms. Significant effort and time was spent in developing and testing radar icing mitigation solutions. A viable solution was developed and tested near the end of the research. Limited preliminary snowplow operator feedback was collected due to lack of snow storms for DAS operational testing and evaluation with the radar icing problem fully resolved.

Due to the lack of snow storms in the research period, and the time spent developing radar icing mitigation solutions, more time is required for testing and evaluation to completely establish whether the DAS would be an effective tool to reduce snowplow operator's exposure to collision and road departure risks in the poor visibility conditions encountered in California, and, if effective, in what ways the system can be adopted by Caltrans.

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Advanced Highway Maintenance and Construction Technology Research Center

Department of Mechanical and Aerospace Engineering
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Evaluation of the University of Minnesota GPS Snowplow Driver Assistance System

Kin S. Yen, Craig Shankwitz, Bryan Newstrom, Ty A. Lasky &
Bahram Ravani (Principal Investigator)

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August 30, 2015

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Division of Research, Innovation and System Information

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The Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center at the University of California-Davis, in conjunction with Caltrans Division of Research, Innovation and System Information (DRISI), identified advanced snowplow driver assistance system (DAS) technology that can significantly enhance the safety and efficiency of snow removal operations in certain parts of Interstate 80 in the Sierra mountains in northern California. The DAS was previously developed at the University of Minnesota and used by the Alaska Department of Transportation (DOT). This research evaluated the DAS as implemented for California operations and provided technical support for DAS implementation. The research included collaboration with the University of Minnesota and MTS System Corporation to instrument two snowplows and one snow blower with DAS to support scientific testing and evaluation.

A Global Navigation Satellite System (GNSS) base station was established at Kingvale maintenance station in support of the DAS operation. The DAS GNSS receivers' performance was evaluated. The DAS radar unit experienced icing during heavy snow storms. Significant effort and time was spent in developing and testing radar icing mitigation solutions. A viable solution was developed and tested near the end of the research. Limited preliminary snowplow operator feedback was collected due to lack of snow storms for DAS operational testing and evaluation with the radar icing problem fully resolved.

Due to the lack of snow storms in the research period, and the time spent developing radar icing mitigation solutions, more time is required for testing and evaluation to completely establish whether the DAS would be an effective tool to reduce snowplow operator's exposure to collision and road departure risks in the poor visibility conditions encountered in California, and, if effective, in what ways the system can be adopted by Caltrans.

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Definition
2D	Two-dimensional
3D	Three-dimensional
AHMCT	Advanced Highway Maintenance and Construction Technology Research Center
ATX	Advanced Technology eXtended
BNC	Bayonet Neill–Concelman
Caltrans	California Department of Transportation
COTS	Commercial Off–The-Shelf
CPU	Central Processing Unit
CSV	Comma-Separated Values
CWS	Collision Warning System
DAS	Driver Assistance System
DDR	Double Data Rate
DGPS	Differential GPS
DLI	Donner Lake Interchange
DOT	Department of Transportation
DRISI	Caltrans Division of Research, Innovation and System Information
ESR	Electronically Scanning Radar
FCC	Federal Communications Commission
FOV	Field of View
FK	Foreign Key
GLONASS	Globalnaya Navigazionnaya Sputnikovaya Sistema
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HARN	High Accuracy Reference Network
HUD	Head-Up Display
IP	Internet Protocol
IV Lab	Intelligent Vehicles Lab
LCD	Liquid Crystal Display
LR	Local Request
NAD	North American Datum
NGS	National Geodetic Survey
OPUS	Online Positioning User Service
PK	Primary Key
PM	Postmile
R&D	Research & Development
RF	Radio Frequency
RGB	Red, Green, Blue
RSSI	Received Signal Strength Indicator
RTK	Real-Time Kinematic
SCP	Secure Copy
SDRAM	Synchronous Dynamic Random Access Memory
SIM	Subscriber Identity Module
SMA	SubMiniature version A
SR	State Route
SSH	Secure Shell
TAG	Technical Advisory Group
TNC	Threaded Neill–Concelman
UCD	University of California-Davis
UM	University of Minnesota

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Acronym	Definition
USB	Universal Serial Bus
VGA	Video Graphics Array
WAN	Wide Area Network

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CHAPTER 1: INTRODUCTION

Problem

Snow removal operations during a whiteout snow storm are one of the most hazardous and difficult tasks that winter maintenance personnel face. Researchers at the University of Minnesota (UM) and the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center, along with our research partners at the California Department of Transportation (Caltrans), have long considered the benefits of providing guidance information to enhance winter maintenance activities [5,7,10,17-19]. The main goal of the snowplow Driver Assistance System (DAS) is to assist the snowplow operator in safely and efficiently performing snow removal. UM has developed an innovative driver assistance system for snowplows using Global Positioning System (GPS) information, an automotive radar, a novel Head-Up Display (HUD), and a haptic feedback seat system using vibrating motors. Their systems are installed on snowplows in Minnesota and Alaska; the technology has been proven to be robust and well-suited for snowplow operations. Caltrans snowplow operators could benefit from this new tool to improve safety and snow removal efficiency. In this research, MTS Systems Corporation (herein referred to as MTS)—who licensed the technology from UM—installed their snowplow DAS on two snowplows and one rotary plow based at the Kingvale maintenance facility on Interstate 80 (I-80). During the subsequent field operational testing of the snowplow DAS, performance was examined and documented to determine if it will improve safety and efficiency of snow removal operations in low visibility conditions and can be successfully implemented in Caltrans' operations. This constitutes the research in this study.

Introduction

The AHMCT Research Center at the University of California-Davis (UCD) worked with UM to deploy and configure a version of the DAS technology for Caltrans winter maintenance operations. A primary goal of this research was to perform a scientific evaluation of such a driver assistance technology to improve safety and efficiency of winter maintenance operations in California.

The UM Intelligent Vehicles Lab (IV Lab) previously developed a Driver Assistive System (DAS) designed to allow the operation of snow removal equipment in low-visibility conditions. This system is based on dual-frequency, carrier phase, real-time kinematic (RTK) differential GPS (DGPS). This DGPS system allows vehicle position to be determined with accuracy better than 3 in (8 cm) at a data rate of 10 Hz. Combined with the DGPS system are a high-accuracy geospatial database, forward-looking obstacle detection sensors, and a comprehensive driver interface consisting of both graphical displays and tactile feedback. The graphical displays include a HUD that enables an operator to locate road lanes and lane boundaries in low visibility and a touch screen-based system information/control panel. The tactile interface consists of a vibrating seat that indicates lane departure situations by vibrating the seat bottom on the side where lane departure is imminent. Details of the system are available in UM IV Lab publications [1-5,7-12].

I-80 at Donner Pass is one California area for which a reliable DAS is needed. The preview system developed by the IV Lab is appropriate for such areas. This research proposed to obtain

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this system from UM, tailor its configuration for California, and use it to perform research on improvement of safety and efficiency of winter maintenance operations. Part of the work was performed by UM under a purchase order. An additional portion of the work was performed by MTS, also under a purchase order. Technology, intellectual property, and two staff members were spun off from the UM IV Lab into a division of MTS during the course of this research.

AHMCT provided field-testing and deployment support, thus greatly facilitating the transition of the DAS research prototypes into broader use within Caltrans. This represents a significant added value for the implementation by University of Minnesota and MTS. Furthermore, AHMCT used the system as a research instrument for evaluation and testing to perform scientific studies on improving safety and efficiency of winter maintenance operations. The methodologies developed by AHMCT have been carefully crafted to best serve Caltrans' unique research and development needs, and a strong cooperative approach between AHMCT and Caltrans has provided the basis for many successful field tests and deployments.

Working closely with Caltrans to clarify their winter maintenance needs and requirements, AHMCT evaluated the GPS-based driver assistance systems built and installed by UM and MTS. This research is critical in proving the DAS is suitable for Caltrans' wide-scale deployment on selected routes in California. This new tool has the potential to reduce driver fatigue, improve snow removal safety and efficiency, and increase traffic flow by reducing road closures.

University of Minnesota Driver Assistance System Description

The snowplow DAS functions include lane position indication, lane departure warning, and forward collision warning. The DAS interior and exterior components are shown in Figures 1.1, 1.2, and 1.4. Lane position indication and lane departure warning are displayed on a HUD, as shown in Figures 1.3 (simulated) and 1.5 (actual). The Collision Warning System (CWS) uses a millimeter-wave radar which performs well in the snow environment as it detects vehicles and other inorganic objects. Azimuth angle data allows the system to map detected obstacles to their lateral location, i.e. the system can show the driver what lane the obstacle is located in relative to the snowplow. The system also stores the location of fixed roadside objects in a geospatial database to eliminate false negative collision warnings. Highly accurate vehicle position is provided by the RTK GPS receiver, which can deliver sub-centimeter accuracy under fairly ideal conditions. However, its accuracy is generally recognized to be only centimeter-level under normal operating conditions. Producing a high-accuracy RTK GPS solution requires data from two dual-frequency (L1 and L2) GPS receivers—one stationary base station and one rover—collecting signals from at least five GPS satellites at the same time. The solution can be calculated in real-time by the rover GPS (on the snowplow) when it receives the base station data in real-time through a cellular radio data link.

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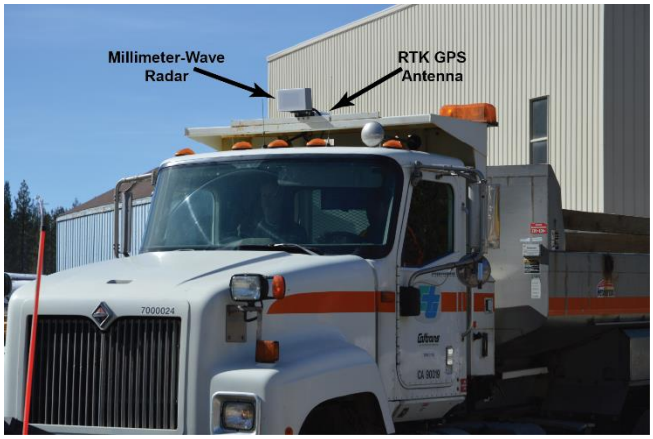

Figure 1.1: University of Minnesota (UM) DAS exterior components

Figure 1.2: UM DAS installed behind passenger seat

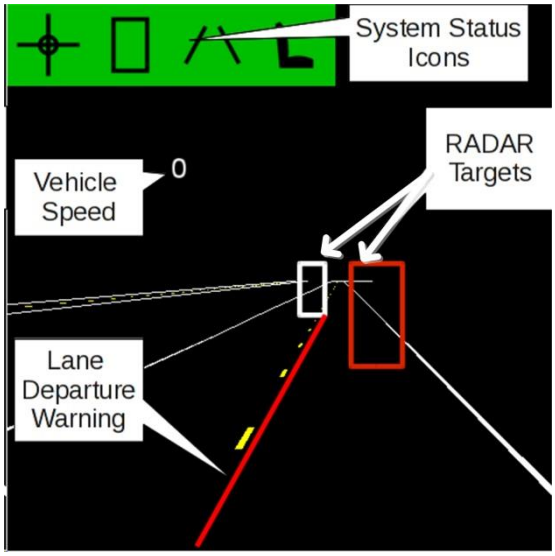

Figure 1.3: UM DAS simulated HUD view

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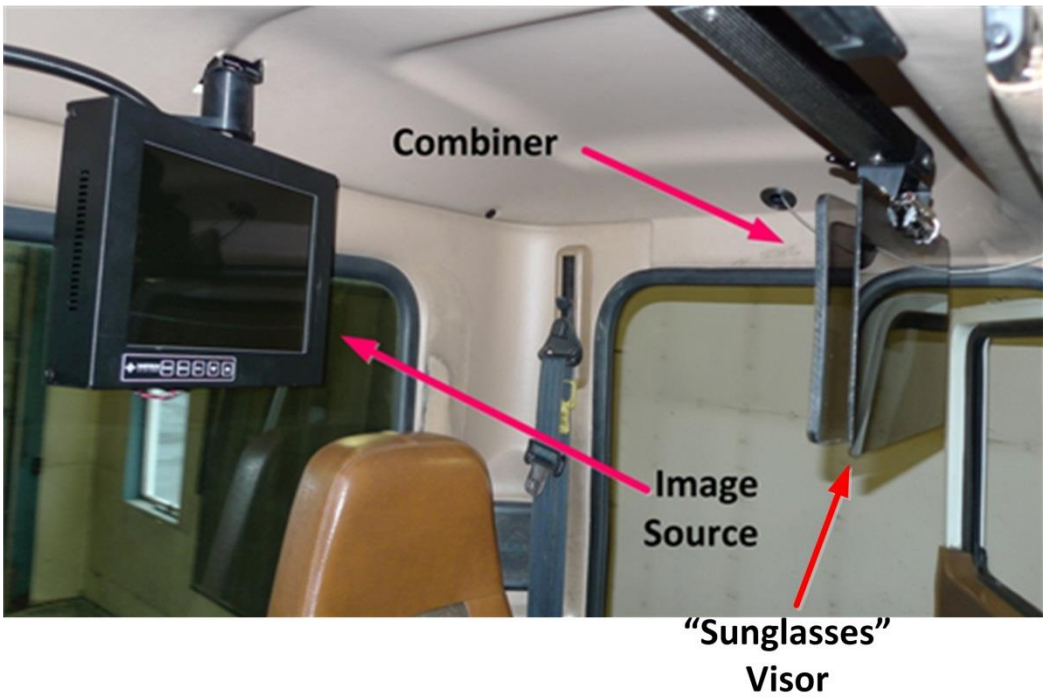

Figure 1.4: UM DAS HUD image source and display combiner

Figure 1.5: DAS viewed from behind driver's seat in a snowplow operating at night. The lane lines and road features are overlaid on the road using the HUD.

Research Approach

AHMCT researchers worked with UM and MTS to implement a version of their snowplow DAS for Caltrans winter maintenance snow removal operations. AHMCT performed evaluation

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and testing of the system. The research objective was to determine if the DAS will improve the safety and efficiency of snow removal operations in low visibility conditions and can be successfully implemented into Caltrans' operations. The research was a necessary step before a wider deployment of this new innovative tool throughout California.

The research snow removal vehicles were based at the Caltrans Kingvale maintenance facility next to I-80. Caltrans snowplow operators used the system in storm conditions starting early in the winter of 2011/2012, and continued each year through the winter of 2014/2015. The system test site is near the Kingvale maintenance station on I-80 in Nevada County, from State Route 20 (SR 20) to Donner Lake Interchange (DLI). It is approximately 50 miles, 25 miles in each direction, of multi-lane highway. The test route is at a high elevation (6,400–7,200 ft). Whiteouts are common in this area due to wind and the sheer volume of snow. The westbound section from DLI to Kingvale often has whiteout conditions due to weather patterns and local terrain. The entire site is located in mountainous terrain, with steep grades and many curves. The location was selected because this portion of I-80 typically closes before other sections of the road due to weather patterns and has a relatively high vehicle per hour traffic count. In addition, I-80 is a vital transportation corridor for commercial goods transportation and tourism for local ski resorts and Reno.

The major research tasks included:

1. Form technical advisory group (TAG)
2. Establishment of a DGPS Base Station at Kingvale, Hardware Procurement for All Systems, Testing and Validation of Components, and Sub-system Design Reviews
3. Establishing Cellular Modem and Securing SIM cards for Communication Needs
4. Monitoring, design reviews, and implementation of the systems on experimental vehicles
5. Evaluation methodology development
6. Vehicle instrumentation and setup for evaluation data collection
7. Ride along for system performance evaluation
8. Snowplow operator interviews
9. Present research results to various groups in Caltrans

The main deliverables included:

1. DGPS base station at Kingvale, final design and configuration of three driver assistance systems: two for snow plows and one for a snow blower
2. Two operational experimental snow plow vehicles, and one operational experimental snow blower vehicle as well as driver training

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3. A data acquisition set up in the two snow plows and the blower for data collection
4. A summary of the data collected in the ride alongs
5. A summary of operators' feedback
6. The results of the data analysis
7. System support for two winters, and this report

All deliverables were met. However, due to the severe drought conditions in California during the research period, the amount of experimental data and operator feedback was insufficient to draw final conclusions about the utility and benefit of the DAS. This is discussed further in Chapter 6. The subcontract could not be established with UM due to flow-through terms that were unacceptable to them. However, we were able to establish a purchase order with UM for the design and development of the two snowplow systems and one blower system. We subsequently established a PO with MTS for continuing work, when the UM IV Lab licensed the related technology to MTS and the two key researchers for this system left UM to work at MTS.

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CHAPTER 2:
SYSTEM INSTALLION AND SETUP

DAS Installation and Training

In 2012, DAS were installed in two snowplows (Caltrans vehicle # 7000506 and 7000024) and one snow blower (Caltrans vehicle # 7005039). Figure 2.1 show the snow blower and one snowplow (7000506) with the DAS installed. All equipment and subsystems were procured by AHMCT so that the system would become AHMCT/Caltrans instrumentation for scientific evaluation and experimentation. When possible, AHMCT tested all components and subsystems to assure they would perform the required operations before installation on the vehicles. The vehicles were provided by Caltrans from their winter maintenance fleet.

Figure 2.1: Snowplow DAS installed on Caltrans snow blower (left, yellow) and snowplow (right, white)

MTS performed the implementation and installation at Caltrans' Kingvale maintenance station. AHMCT researchers assisted in the installation and logistics. Figure 2.1 shows two of the three instrumented vehicles. The computer, modem, and GNSS receiver were installed under the snowplow passenger seat, as shown in Figures 2.3, 2.4, and 2.7. A detailed system design, setup, and operations manual is available in Appendix B. The GNSS base station hardware parts list is provided in Appendix F.

MTS personnel also trained several Caltrans drivers and conducted initial testing of these vehicles for troubleshooting. MTS also did several ride-alongs in the snowplow with Caltrans snowplow operators during snow storms. MTS personnel have also used the experimental vehicles to collect real-time data on system performance. Installation, initial system testing, and training took a total of about four weeks.

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Figure 2.2: DAS user interface and LCD imager display on 700506 snowplow

Figure 2.3: DAS installed under the passenger seat on 700506 snowplow

Figure 2.4: DAS equipment installed under the passenger seat on 700506 snowplow

Figure 2.5: Radar, modem, and GNSS antenna installed on top of the 700506 snowplow cab protector

Figure 2.6: DAS user interface and vibration seat control on 700024 snowplow

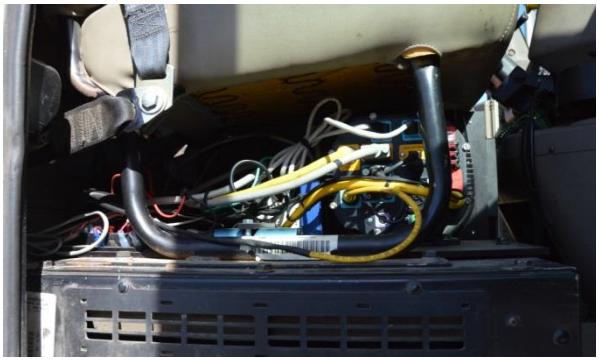

Figure 2.7: DAS equipment installed under the 700024 passenger seat

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Figure 2.8: DAS exterior components (radar & GNSS antenna) on snow blower

Figure 2.9: GNSS antenna & modem antenna mounted on snow blower

Figure 2.10: DAS HUD combiner mount in the snow blower

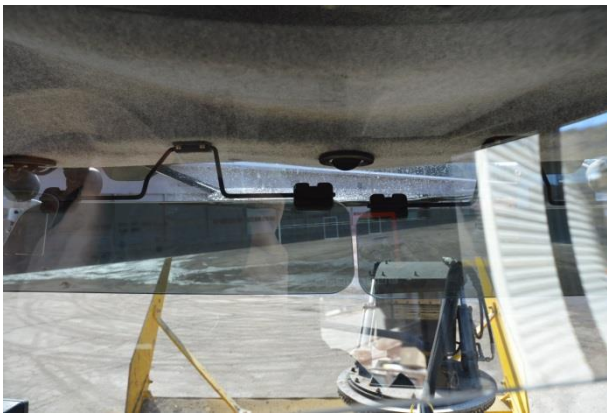

Figure 2.11: Driver's view looking through the combiner in the snow blower

Figure 2.12: DAS equipment mounted next to the operator's seat in the snow blower

Figure 2.13: DAS control interface in the snow blower

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Figure 2.14: DAS viewed from behind driver's seat in a snowplow operating at night. The lane lines and road features are overlaid on the road using the HUD.

GNSS Base Station Setup

A GNSS base station was installed at the Caltrans Kingvale maintenance station Command Center in the summer of 2012. This base station provides differential GNSS data to the DAS GNSS receiver. The GNSS base station (Trimble NetR9 Ti-1 Reference Station using a Trimble Zephyr Geodetic 2 antenna with integrated radome antenna) is essential in providing a high-accuracy vehicle position solution from the GNSS receiver on the snowplow or snow blower. AHMCT staff installed the GNSS base station antenna and cellular modem antennas on the exterior of the Kingvale Command Center, as shown in Figure 2.15. The GNSS base station receiver and modem are mounted on a shelf near the ceiling. The installation location was selected with Caltrans' assistance and input, so that its impact to Caltrans operations is minimal. A detailed list of the GNSS base station hardware is available in Appendix F. A PolyPhaser SSM - DC Pass Coax Protector was used for lightning protection. In addition, a Seco 2072-31 303 stainless steel adapter was used to mount the GNSS antenna onto the 2.5" pipe. The adapter provided precise tilt adjustment for leveling the GNSS base station antenna.

MTS configured the GNSS base station and mobile network modem to work with the DAS on the snowplows and snow blower. MTS personnel also surveyed the precise location of the GNSS base station antenna using the Online Positioning User Service (OPUS) provided by National

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Geodetic Survey (NGS)[1]. The GNSS base station antenna location solution provided by OPUS is available in Appendix A.

A cell modem provides Internet connection to the GNSS base station. AT&T was the initial cellular service provider. However, their mobile Internet service does not allow their AT&T modems to talk directly to each other. Thus, the snowplow or snow blower (i.e. the rover) GNSS receiver could not receive differential GNSS data from the base station. AT&T technical support was unable to resolve this problem. AHMCT then tested Verizon modems and mobile network services. The Verizon setup worked without any special configuration. Thus, Verizon modems and service were used in this research.

Figure 2.15: GNSS base station antenna and mobile network antenna installation at Kingvale Command Center

[1] OPUS described at http://www.ngs.noaa.gov/OPUS/about.jsp with OPUS file upload form at http://www.ngs.noaa.gov/OPUS/

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Figure 2.16: GNSS base station receiver and mobile network modem installation at Kingvale Command Center

Figure 2.17: GNSS base station antenna functioning under heavy snow cover

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CHAPTER 3:
MAPPING

A detailed, high-accuracy digital map is another key component of the DAS. The majority of the current DAS digital map was surveyed by MTS personnel. Using the GNSS base station established in Kingvale, they drove along I-80 and mapped the roadway with an RTK GNSS receiver. The resulting high-accuracy digital map covered I-80 from State Route 20 (SR 20) interchange to DLI. The WGS84 bounds are (-124.0700, 38.0300); (-119.5400, 40.1500). The projected bounds are (1818261.6061, 542403.4865); (2215971.2605, 778520.4568). Here, the coordinates are given as (longitude, latitude). The digital map includes lane marking, edge of pavement, guardrail, median crossings for snowplow turn-around, and large signs. Drainage inlets were added later for snow blower operations. Detailed map documentation provided by MTS is available in Appendix I.

The project area was later surveyed and mapped using the Caltrans Mobile Terrestrial Laser Scanner (MTLS) [13-16]. The resulting point cloud was used to extract the inlet locations and outlines for the snow blower. The inlet .shp (Shapefile, a popular geospatial vector data format for geographic information system (GIS) software, developed and regulated by Esri[2]) files were first created in the EPSG:2767, NAD83 (HARN) / California Zone 2 State Plane map projection[3]. QGIS open-source software was used in the data conversion and post-processing[4]. The inlet .shp files were then sent to MTS for verification and final processing. A donnerpass.zip digital file, which contains all the DAS digital maps files, was returned for unloading onto the snow blower computer. The contents of the donnerpass.zip file are available in Appendix I. Appendix I also illustrates the map updating process for the snow blower.

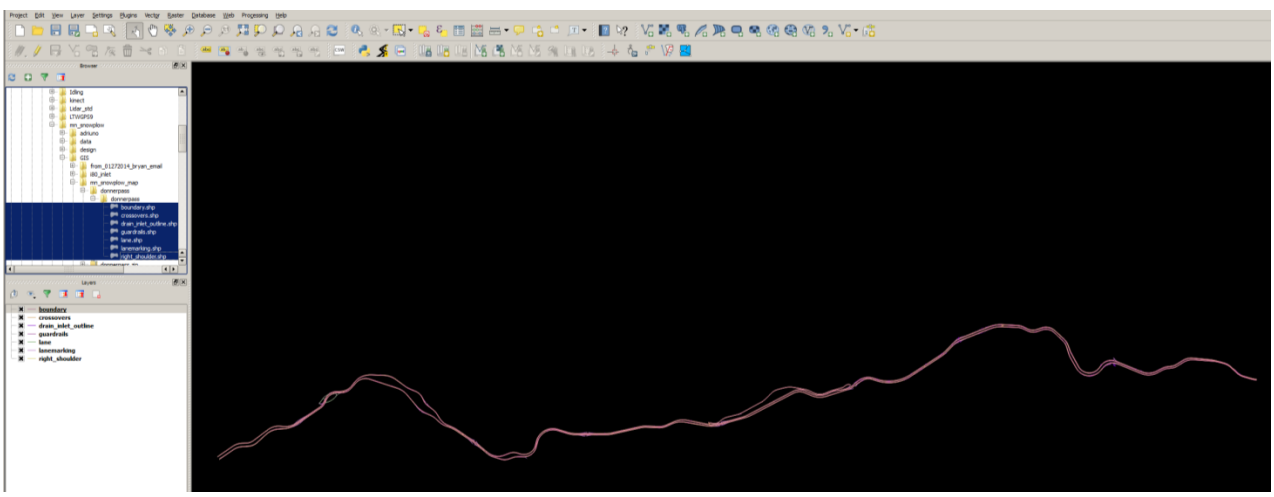

Figure 3.1: All DAS map layers SHP files displayed on QGIS

[2] https://en.wikipedia.org/wiki/Shapefile with details at http://www.esri.com/library/whitepapers/pdfs/shapefile.pdf
[3] http://www.epsg.org/ and North American Datum and High Accuracy Reference Network
[4] http://www.qgis.org/

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CHAPTER 4:
RADAR ICING ISSUE

Problem

During this initial testing, there was occasional buildup of ice on the front fascia of the Commercial Off–The-Shelf (COTS) radar (Delphi Electronically Scanning Radar, or ESR) made by Delphi Automotive PLC. This ice and water layer attenuated the radar signal on send and receive. This interference was caused by a thin layer of water trapped on the radar front fascia by the buildup of wet snow and ice. The thin water layer on the radar front absorbed a majority of the 76 GHz radio signal, rendering the radar ineffective. This water layer buildup and signal attenuation problem was not reported by Alaska or Minnesota during their use of similar systems and is attributed to the type of snow prevalent in the Sierras. The phenomenon was new and unexpected to UM, MTS, and AHMCT researchers. AHMCT researchers have previously used COTS radar for snowplow driver assistance [17-19]. AHMCT noted ice buildup on the COTS radar, but it did not cause any radar performance degradation. However, the previously used COTS radar, now out of production, employed 24 GHz radio frequency (RF) for object detection. The ice/water RF signal attenuation for 24 GHz is much less than for the 76 GHz RF used by the Delphi ESR. The Federal Communications Commission (FCC) dedicated the 76 GHz frequency for automotive collision warming radar use. Therefore, most current COTS automotive radar systems available in the United States use 76 GHz RF. A significant effort was made by AHMCT researchers to resolve the radar icing issue before detailed operational testing and evaluation of the snowplow DAS could begin.

Solution Development

Heated Enclosure

To mitigate this problem, the Delphi electronically scanning radar (ESR) dealer AutonomouStuff[5] developed heated enclosures for the ESR (see Figure 4.1 - 4.3). The heated enclosure consists of a hydrophobic plastic (Delrin) front fascia shown in white in Figure 4.2, heating resistors shown in gold in Figure 4.3, a temperature controller shown in blue in Figure 4.3, and an aluminum enclosure with watertight connectors for the heater and radar. The temperature controller is essential in keeping the heater from overheating the radar electronics inside the enclosure. The resistors are each 6.8 ohms and can theoretically generate a total of 42 watts of heat using a 12 volt power supply. However, due to wire loss (voltage drop across the line), they can only generate 36 watts maximum (3.5 amp draw). The modified enclosure was tested in Idaho.

[5] www.AutonomouStuff.com

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Figure 4.1: Heated enclosure back

Figure 4.2: Heated enclosure front

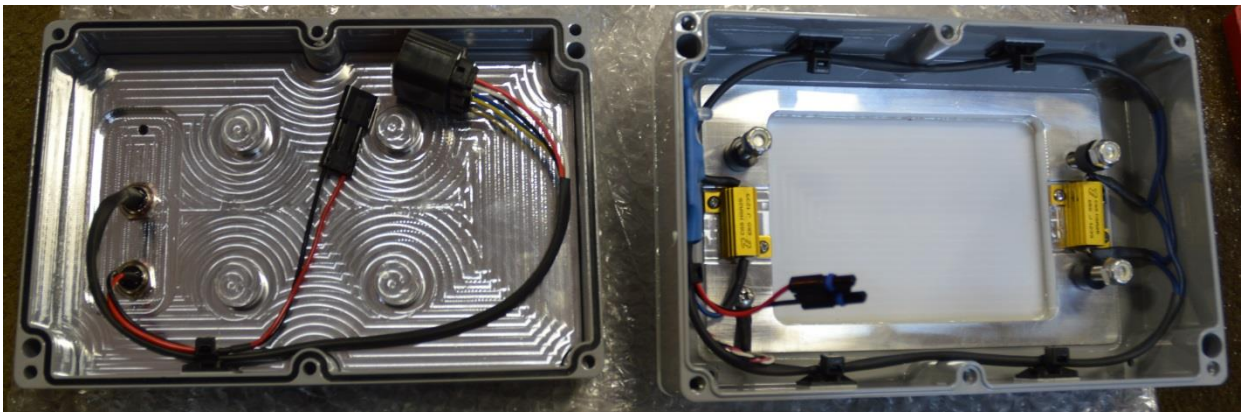

Figure 4.3: Inside of the ESR heated enclosure

AutonomouStuff also experimented with an air knife to blow the snow and ice away. Test results showed that this approach is ineffective in reducing icing—the air knife mounted above the heated enclosure, as shown in Figure 4.4, was completely iced up in simulated snow storms. In Figure 4.4, the black rectangular object on the right is the ESR without enclosure; the white box is the heated radar enclosure; and the object above the heated enclosure is the air knife.

Finally, AutonomouStuff tried a couple of different anti-ice and hydrophobic coatings on the fascia. They found that the coatings were reasonably durable, but long-term testing is needed. They sent samples to Delphi for them to characterize the RF attenuation from several different anti-ice and hydrophobic coatings. Delphi found that the best coating had unacceptable attenuation (> 3 dB). The products tested were from MicroPhase Coatings, PhaseBreak HT, TP, and Flex. MTS researchers did try mounting the radar behind glass in Minnesota, but the glass attenuated too much RF signal. Rust-Oleum NeverWet hydrophobic treatment was also tested and found not sufficiently durable.

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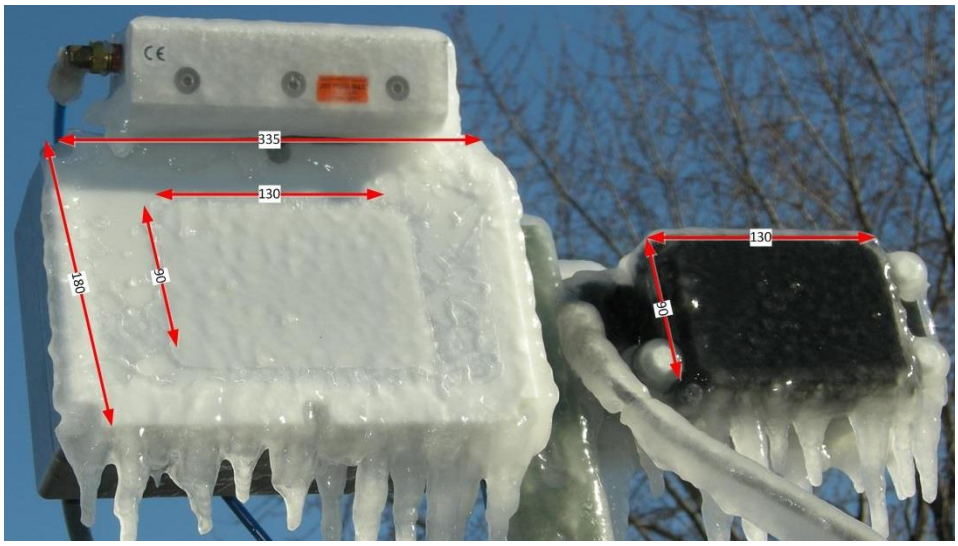

Figure 4.4: AutonomouStuff radar enclosure test setup (photo provide by AutonomouStuff)

ESRs were mounted inside the heated enclosures purchased from AutonomouStuff for testing on the snowplow and an AHMCT test vehicle. Subsequent testing showed that the heaters were underpowered to melt and eliminate the wet snow build-up when the vehicle speed is high (~35 mph) and under heavy snowfall. Figure 4.5 shows icing on the heated fascia after driving in a heavy snow storm at about 30 mph. However, the heater was adequate in keeping ice from forming when the vehicle is stationary. Because of the slow speed of the snow blower, the heated radar enclosure should be effective in keeping the wet snow and ice build-up under control on the snow blower; however due to the lack of heavy snow storm, the snow blower was not used in the past few years. This testing showed that the heated enclosure from AutonomouStuff does not solve the radar icing problem for the snowplows.

Figure 4.5: Icing on the heated radar enclosure

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Figure 4.6 showed a thermal image of the heated fascia (on the right) next to a photo of the enclosure. The thermal image illustrates that the center of the fascia is cold (registering at freezing temperature) while the temperature near the heating element is hot. This distribution is due to the poor thermal conductivity of the fascia plastic. The temperature of the aluminum housing side is also higher than that of the fascia plastic front. Therefore, significant heat is lost to the side of the higher thermal conductivity aluminum housing. The heating element should be insulated so that all the heat generated is transferring to the front fascia.

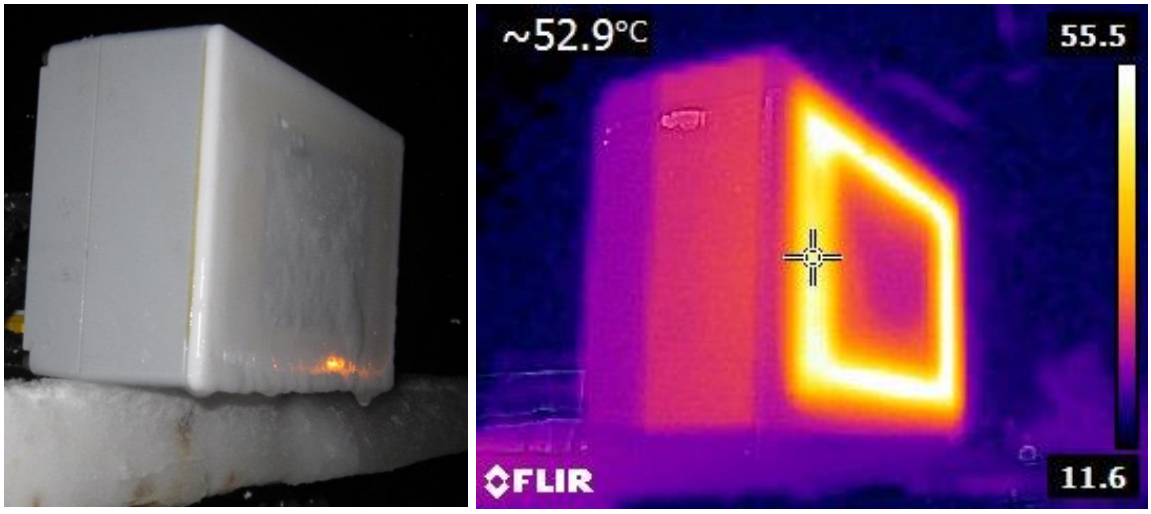

Figure 4.6: Icing on the heated radar enclosure, including thermal image on right

Due to additional current draw by the enclosure heater, there was significant voltage drop in the power supply (to about 11 volts), as shown in Figure 4.7. This was caused by undersized wiring. The supply voltage drop caused the GNSS receiver to shut down when the enclosure heater was on for a period of time. The GNSS receiver was programmed to automatically shut down when the power supply voltage drops below 11.4 volts, resulting in system failure. Once this problem was identified, the GNSS receiver was reconfigured to shut down at 10.8 volts. In addition, heavier gauge (10-gauge) wires were used to replace the original, undersized wiring. The GNSS receiver did not shut down after these revisions.

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Figure 4.7: Trimble GNSS receiver web user interface showing power supply voltage at 11.08 v when heater is running

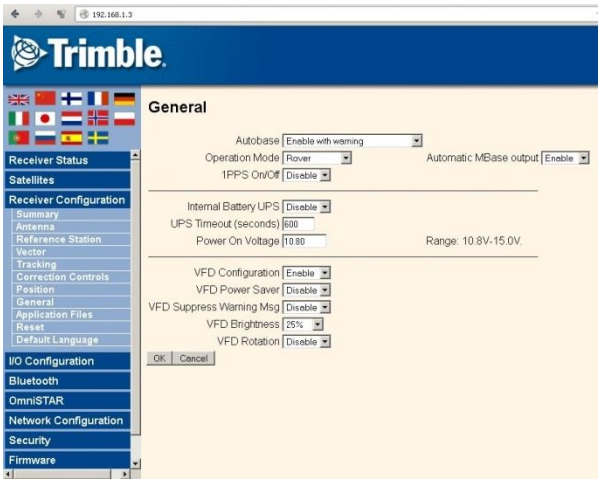

Figure 4.8: Trimble GNSS receiver web user interface showing power on voltage set to 10.8 v

Based on estimated snow fall rate, snow water content, vehicle speed, and the frontal area of the fascia, the minimum heater power requirement is about 350 watts (29 amps at 12 volts). The power requirement could be reduced by reducing the fascia front area. The existing snowplow alternator can supply 130 amps when the vehicle is moving. It does not generate enough power for the combination of the radar heater and other on-board equipment such as lights, heater blower, DAS, and voice radio. Therefore, a heated enclosure alone is not a viable solution. The addition of a wiper would be a more energy efficient solution. This would avoid upgrading the on-board alternator.

Hydrophobic Coatings

AHMCT, MTS, and the radar vendor also explored various hydrophobic coatings as an additional component of addressing the radar freezing problem. Figure 4.9 shows that ice and snow sticks to the polycarbonate plastic coated with Rust-Oleum NeverWet hydrophobic coating. A hydrophobic coating alone may not solve the icing problem.

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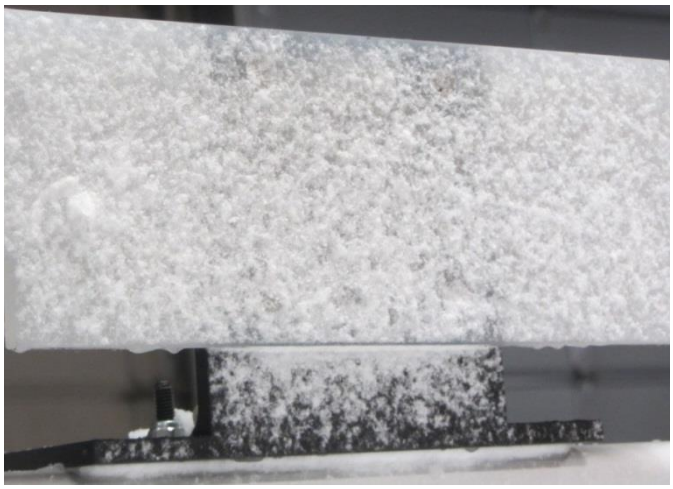

Figure 4.9: Icing on polycarbonate plastic coated with Rust-Oleum NeverWet after driving in a snow storm

Heated Enclosure with Wiper

AHMCT, MTS, and the radar vendor explored additional solutions to the icing problem. Delphi Automotive was consulted through AutonomouStuff. A wiper blade has been mounted to the heated radar enclosure to determine its effectiveness, as shown in Figure 4.10. The first-generation wiper system failed due to snow and ice sticking to the wiper blade, and the wiper blade did not apply sufficient pressure onto the fascia to push snow away. Furthermore, the wiper motor was a COTS system developed for the military market. It was highly programmable in its range of motion, but very expensive. Nevertheless, the first generation design provided important insight to future wiper design improvement:

- A heated wiper blade is required
- The wiper blade must also move to an open area to allow the wind to blow away the snow on the wiper blade.

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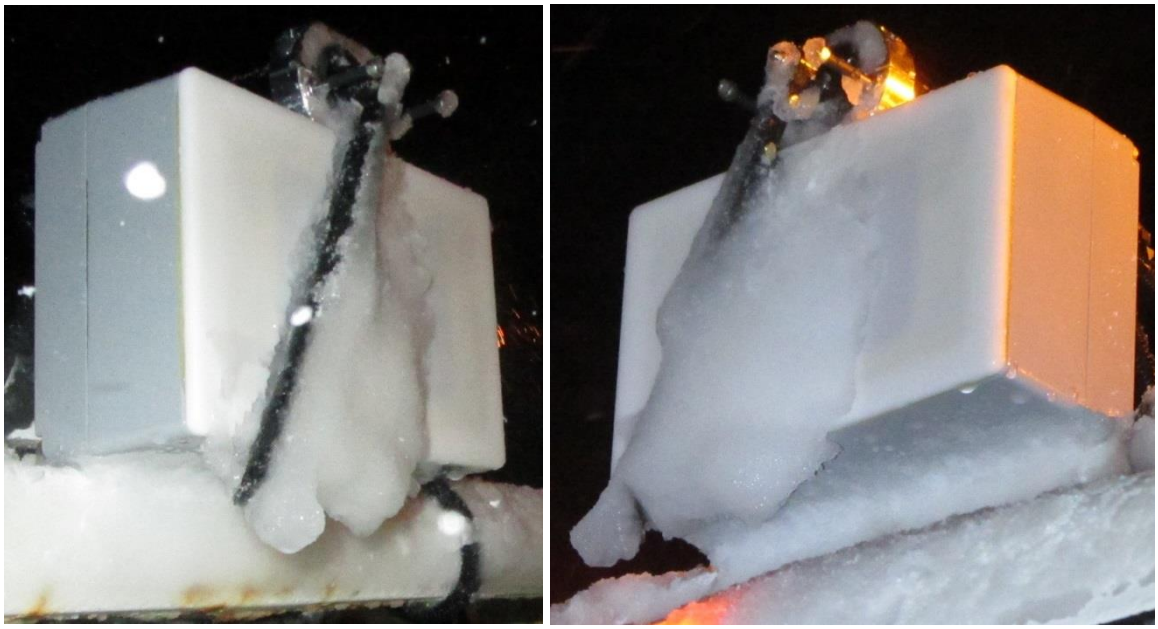

Figure 4.10: First-generation wiper / heated enclosure system

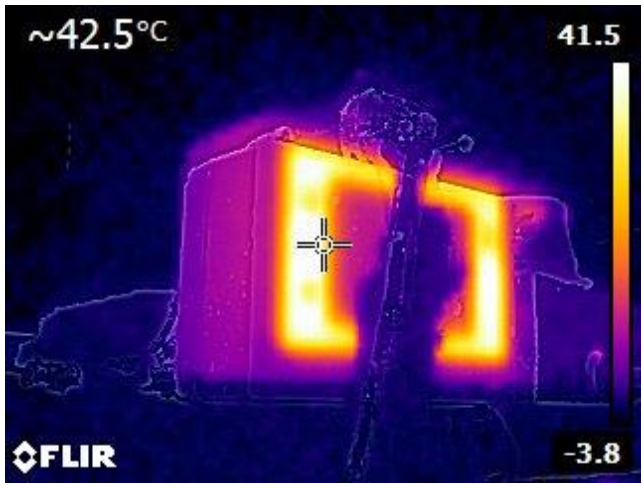

Figure 4.11: Thermal image of the first-generation wiper / heated enclosure system

Heated Enclosure with Heated Wiper

A COTS marine wiper motor was chosen in the next-generation design for its long-term availability and low cost. Since the first-generation wiper design test showed that snow sticks to an unheated wiper blade, a COTS heated wiper blade manufactured by THERMABLADE was selected to keep ice and snow from freezing on the wiper blade and blocking the radar. The 12" silicone heated wiper blade has an air spoiler that keeps the blade firmly on the surface while driving at high speeds. The silicone wiper blades should last longer than rubber blades. The wiper is thermostatically controlled to automatically heat when freezing conditions exist. The wiper blade heater draws 1.3 amps. The second-generation design is shown in Figure 4.12. The second-

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and third-generation designs failed when the snow fall was heavy for an extended period. The cause of failure is snow accumulation on the side of the fascia by the wiper blade pushing snow to the accumulation area. The snow build-up diminished the ability of the wiper blade to push snow from the center of the fascia.

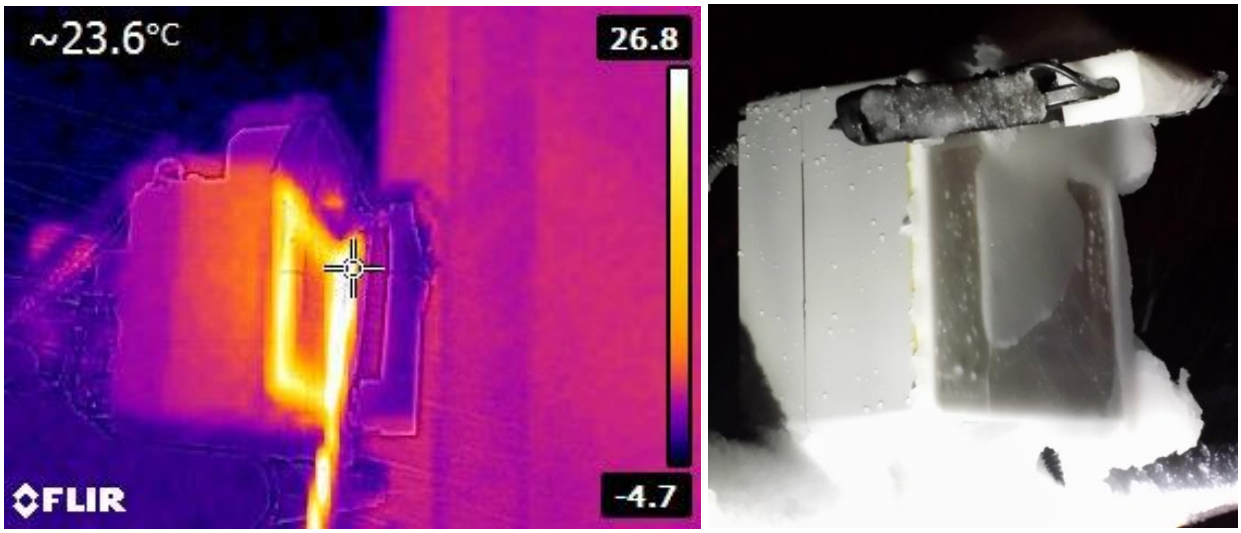

Figure 4.12: Second-generation wiper design (wiper motor mounted on top) with heated wiper blade, including thermal image on left

Figure 4.13: Third-generation wiper design (wiper motor mounted on bottom) with heated wiper blade

The final wiper / heated enclosure design is shown in Figure 4.14. The COTS marine wiper motor was mounted to the side and below the heated enclosure. Thus, any build-up of snow and

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ice on the motor face and mount will not hinder the wiper operation. In addition, two black narrow plastic supports were added to the bottom and side of the enclosure. The supports allow wind to blow the snow and ice off the wiper blade and themselves, preventing snow and ice accumulation. Insulation was added behind and to the side of the heating element to focus the heat transfer toward the front fascia. Figure 4.15 shows that the final wiper design with heated wiper blade passed operational tests. Snow accumulated in areas surrounding the radar, but not on the fascia. The final radar wiper system was installed and tested on both 700024 and 700506. The final radar wiper system seems to work well and prevented ice from forming during the testing in the 2014 - 2015 snow season.

Figure 4.14: Final wiper design with heated wiper blade

Figure 4.15: Final wiper design with heated wiper blade. This design passed operational testing. Snow accumulated in areas surrounding the radar, but not on the fascia.

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However, there were not many heavy snow storms in the past few years to sufficiently test the heated enclosure and wiper system. More testing is needed to ensure the radar heater/wiper system will work under heavy snow conditions and have good reliability. More ride-alongs and testing during heavy storms are needed to prove the system performance. Nevertheless, with the existing results, the operational testing and evaluation of the entire DAS can begin.

Future Work and Testing

- Control the wiper cycle frequency based on vehicle speed to reduce wiper blade wear. Use GPS for speed sensing.
- Redesign enclosure with smaller front area and increase heater output.
- Experiment with embedding heating wires in the front fascia.
- Upgrade snowplow alternator to provide more power for the heater.
- Replace Delrin with Teflon for the front fascia material. Teflon has a better hydrophobic property.

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CHAPTER 5:
TEST RESULTS

Three DAS were installed (two snowplows and one snow blower). The systems performed well during initial testing. To facilitate testing and subsequent analysis and evaluation, the HUD combiner position (up/down), vehicle position, number of satellites, estimated positional accuracy, collision warning data, and the position of front plow blade (up/down) are logged when the DAS is running. A detailed comma-separate values (CSV) text log file example is provided in Appendix H. Video recording equipment was employed to record the system general operations. The recorded video was provided to Caltrans DRISI. Data reduction and analysis was performed to evaluate RTK GNSS availability and mobile network signal strength. The AHMCT researcher had several ride-alongs with different snowplow operators to observe real-time DAS performance and operator interaction.

Data Analysis

Mobile Network Signal Availability

To provide sub-inch-level (centimeter-level) accuracy position calculating to the DAS system, the DAS GNSS receiver requires a network link to receive differential GNSS data from the GNSS base station. Without the mobile network link, the GNSS positional accuracy will not meet the DAS accuracy requirement and the DAS system will not function properly. Using the PowerMeter app developed by AHMCT [6], we surveyed the cellular network coverage in the Kingvale test area for both AT&T and Verizon. Our results show that the Verizon network provides better signal strength and coverage in the Kingvale test area; hence, we selected Verizon for cellular data transmission. A 3G Verizon modem was used, since a 4G modem was not available at the time of modem purchase. The use of the PowerMeter app at the outset of the project supported the decision to use cellular communications for differential corrections, rather than more complex and expensive RF communications.

Table 5.1: RSSI color key

Color	RSSI
Dark Green	0 to -70 dBm
Light Green	-70 to -80 dBm
White	-80 to -95 dBm
Orange	-95 to -100 dBm
Red	-100 to -150 dBm

The received signal strength indicator (RSSI) in dBm was logged in the DAS log file along with the vehicle position. The data were overlaid on a Google hybrid map and analyzed in QGIS. Each color dot represents different RSSI range as listed in Table 5.1. RSSI below -100 dBm is considered poor signal with limited connectivity. Figure 5.1 shows the Verizon mobile network coverage of the entire test area (on I-80 from SR 20 interchange to DLI). The red dotted areas (at, and east of, Soda Spring and DLI) shows poor signal strength.

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Figure 5.1: RSSI on I-80 from SR 20 to DLI overlaid a Google hybrid map

Figure 5.2 show that the Verizon network coverage on SR 20 had few large sections without good RSSI. Figure 5.3 displays the RSSI from Kingvale to DLI; and Figure 5.4 shows the RSSI at DLI. This shows that the network coverage is poor at DLI. The overall Verizon mobile network coverage for the test area was good with only a couple of areas with poor signal. When cellular signal is lost, the system will not receive RTK differential correction. The impact of this is discussed below and in Appendix B. These results are good, considering that the test area is mountainous and rural.

Figure 5.2: RSSI on SR 20 overlaid on a Google hybrid map

Figure 5.3: RSSI on I-80 from Kingvale to DLI overlaid on a Google hybrid map

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Figure 5.4: RSSI on I-80 at DLI overlaid on a Google hybrid map

Differential RTK GNSS Availability

An accurate vehicle positioning solution from the GNSS receiver is vital to DAS operation. Without an RTK GNSS solution (centimeter-level accuracy), the DAS will not display the map overlay on the HUD. The GNSS solution status is an indicator for the positional accuracy. Several log files were combined to plot and overlay GNSS solution status on a Google hybrid map using QGIS software. Table 5.2 provides the color key to the GNSS solution status. RTK float or RTK fixed solution are required for the DAS to function. Figures 5.5 and 5.6 show that the GNSS receivers were producing RTK fixed solutions in the overwhelming majority of the test area.

As discussed in Appendix B, RTK fixed is the desired GNSS solution, with accuracy around 0.8 in (2 cm). The system will still provide lane guidance with RTK float GNSS solution with accuracy around 8 in (20 cm). Any lower accuracy GNSS solution is insufficient for DAS lane guidance; thus, the system will not provide lane guidance. Hence, in the below figures, guidance would be provided for blue (best) and green (sufficient) areas, but not for yellow, orange, or red. The details for indicating system status are provided in Appendix B under the section "HUD Status," including GNSS status and position accuracy, radar collision warning status, and lane guidance status. The display provides clear indication to the operator if it is not providing lane guidance (visual or tactile) or radar collision warning. If the differential signal is lost, e.g. in areas without cellular data connection, the snowplow GNSS can rely on previous differential data for a short period. The amount of time depends on multiple factors, including distance from the GNSS base station to the snowplow, number of satellites in view, and GNSS receiver internal processing algorithm specifics.

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Table 5.2: GNSS positional solution color key

Color	Solution ID	GNSS Solution Status
Red	0	No solution
Orange	1	Autonomous (no correction)
Yellow	2	DGPS (3.3 ft-level, meter-level accuracy)
Green	3	RTK float (4 in-level, decimeter-level accuracy)
Blue	4	RTK fixed (0.4 in-level, centimeter-level accuracy)

Figure 5.5: GNSS RTK solution status on I-80 from Kingvale to DLI overlaid on a Google hybrid map

Figure 5.6: GNSS RTK solution status on I-80 from SR 20 intersection to Kingvale overlaid on a Google hybrid map

Figure 5.7 shows that the GNSS receivers were not providing accurate solution on SR 20. Thus, the DAS does not work well on SR 20. However, SR 20 was not an area of interest for the DAS. Figures 5.8-5.10 display small areas where the GNSS solution is not accurate for DAS due to GNSS signal blockage when the snowplow drives under a bridge. This issue is discussed below.

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Figure 5.7: GNSS RTK solution status on SR 20 overlaid on Google hybrid map

Figure 5.8: GNSS RTK solution status on I-80 at Kingvale area overlaid on a Google hybrid map

Figure 5.9: GNSS RTK solution status on I-80 at Soda Spring overlaid on a Google hybrid map

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Figure 5.10: GNSS RTK solution status on I-80 at DLI overlaid on a Google hybrid map

The GNSS receivers on board the DAS snowplow produce accurate position solution for DAS in the overwhelming majority of the test area. However, there were small gaps in a few areas where the solutions were not sufficiently accurate for DAS. The inaccurate solutions are primarily due to GNSS signal blockage by bridge structures or tall trees. The GNSS reacquisition time after the solution is lost due to bridges or trees can be as low as one second, but will vary based on several factors: distance from the GNSS base station to the snowplow, the number of satellites in view, the GNSS base station differential data age, and the GNSS receiver internal processing algorithm. The response of the system to degraded GNSS solution in terms of providing lane guidance are discussed above and in Appendix B. It is essential that operator training includes clear discussion of the meaning of the various display modes. In particular, operators must understand when the system is not providing lane guidance or collision warning, and what to do if this occurs for a prolonged period in whiteout conditions. As long as the operator is well-trained, this should not represent a safety issue.

Ride-alongs for System Performance Evaluation

In addition to logging the system operational data, the AHMCT researcher had many ride-alongs with the snowplow operators using the DAS throughout the winter seasons. During the ride-alongs, the researcher observed the system operation in real time and assessed the system performance characteristics. The researcher also looked for any anomalies, such as collision warning fault (both false positives and false negatives), along with lane positioning accuracy and reliability. Due to the radar icing issue, ride-alongs were performed in most of the major snow storms. The ride-alongs focused on the radar icing issue and operator training. While Caltrans has some experienced snowplow operators, some operators are less experienced and only work during the snow storm events. There were frequent changes of the snowplow operator on the DAS snowplow. Some operators had no experience with the DAS, so that training was often required. However, the main snow removal operation took priority, and DAS training was carried out when the operator workload was low. In addition, the number of major snow storms was relatively small in the last few years. The operators experienced very small numbers of whiteout conditions. As a result, the DAS was not used except for training and testing.

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Informal Snowplow Operator Feedback and Researcher Observation

The Caltrans snowplow operators are invaluable resources, not only for testing the system, but for providing input and guidance for future improvement of the DAS. The AHMCT researcher talked informally to many snowplow operators to seek their feedback.

Snowplow operator feedback and AHMCT researcher observations:

- All operators like and provided positive comments on the vibrating seat feature.
- Operators often put the HUD combiner off to the side instead of directly in front of their field of view (FOV). They do this in order to split their FOV between an unobstructed view of the roadway and the HUD combiner.
- It is difficult to see the image overlay on the combiner during daylight. The tinted sun visor produced too much glare and internal reflection that obscured forward visibility of the roadway.
- The combiner is too large. It is difficult to move it into position without hitting the LCD display or other objects inside the cab.
- The DAS snowplow was not used as a lead plow in the echelon plowing formation.

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CHAPTER 6:
CONCLUSIONS AND FUTURE RESEARCH

The research was successful on many fronts, but could not achieve all of its goals due to a lack of heavy snowfall events and whiteout conditions in the severe drought conditions prevalent in California during the research. Three vehicles were instrumented (two snowplows and one blower). A GNSS base station including needed cellular data communications was established at Kingvale. A base map was generated for I-80 in the Kingvale area. This base map was updated after construction changed the roadway configuration. The map update was performed using advanced mobile laser scanning and post-processing techniques. This update included identification and precise location of drainage inlets which is important for snow blower operation. However, the installed DAS systems could not be sufficiently tested due to weather conditions. In fact, the snow blower was not tested in operation at all, as there was never sufficient snow buildup to justify use of a snow blower during the research. In addition, significant radar freezing issues were encountered during the research. Addressing this problem was a significant engineering challenge. We believe we have addressed the issue; however, further testing in future research under heavy snowfall is required.

Research Findings

- Due to lack of heavy snowfall, the snow blower was not used during the past few winter seasons.

- A significant part of the research effort and time was spent developing a radar icing mitigation solution. A viable solution (heated enclosure plus wiper with heated blade) was developed toward the end of the research. The development process was slow due to the lack of heavy snow storms in the past few years. This prevented adequate testing of the developed solution.

- Due to the radar icing problem, field operational testing did not start until near the end of the research.

- The 3G modems in the AT&T wide area network (WAN) could not communicate with each other.

- The Verizon WAN provided better coverage on I-80 from SR 20 interchange to DLI.

- The GNSS receivers on board the DAS snowplow produced an accurate solution for the DAS in the overwhelming majority of the test area. However, there were small gaps in a few areas where the solution was not sufficiently accurate for DAS. The inaccurate solutions are primarily due to GNSS signal blockage by bridge structures or tall trees.

- All operators liked and provided positive comments for the vibrating seat feature.

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Future Work and Recommendations

- Currently only a 3G modem was used for the communication link between the GNSS base station and the GNSS receiver on the DAS snowplow. A 4G LTE modem will decrease latency, increase bandwidth, and may increase coverage. The Verizon LTE 750 MHz RF band theoretically will provide longer range and better propagation in mountainous area due to its lower radio frequency compared to 3G frequencies (850 MHz and 1900 MHz). The modem should be upgraded and tested for performance.

- The snowplow alternator should be upgraded to higher power output alternator in future DAS installations. This should be included in the Caltrans LR (Local Request).

- The current roadway image overlay does not utilize the entire combiner. A smaller combiner would be easier to move into position. It would also obscure a smaller portion of the driver's FOV.

- An LCD with higher contrast, darker black, and high brightness would improve the roadway image overlay. However, this improvement is limited by available COTS LCD displays.

- Daylight visibility of the HUD imagery could be improved in several ways. It would be improved by multi-coating to reduce glare. A smaller combiner would also help—this would address multiple issues, and MTS may already be considering this. Finally, use of a curved sun visor to match the curve of the combiner should also help. Any of these changes would require negotiation with the system manufacturer, MTS, and will impact the cost.

- The radar icing mitigation solution worked well. However, more testing is needed to evaluate its reliability.

- The GNSS receiver works well in providing accurate positional solution throughout the test area. However, there were a few small gaps where an RTK GNSS solution is not available. Integration with an inertial measurement unit would reduce these gaps and improve system availability. On the other hand, this would increase the system cost.

- Due to frequent snowplow operator changes, ongoing training is needed to enlarge the trained operator pool. Concurrently, DRISI has suggested that a review of scheduling methods could be undertaken with the goal of reducing training needs. This should be planned for in deployment.

- Operator training should include discussions on how to handle situations when degraded or lost signals cause the DAS to stop displaying roadway information.

- Due to changes in roadway delineation, there were some small discrepancies between the digital maps and the roadway. The digital maps should be updated and a method developed to ensure mapping updates are completed whenever changes are made to the roadway or shoulder features.

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- Better system integration would reduce installation time, system size, and exposed wiring. MTS has made significant progress in this direction in their recent revisions.

- More testing and evaluation time is needed to determine if the snowplow DAS meets Caltrans' needs and requirements, and to analyze and document the effectiveness of the system. More testing and evaluation is necessary before wider deployment of this innovative tool throughout Caltrans. The primary needs are a winter season or two with a sufficient number of heavy snow storm events, including whiteout conditions, and an active and interested pool of trained operators who are willing to provide candid feedback.

AHMCT is working with Caltrans DRISI and Maintenance to perform continuing system testing, and validation including detailed operator feedback. The current plan is to test the existing systems through the winter of 2015 – 2016, with the hope that proper testing conditions (sufficient number of heavy storms with whiteout conditions) are available. Under this planned work, AHMCT will train operators to use the system, perform ride-alongs to evaluate the system and its use, and solicit operator feedback. With proper testing conditions, this should allow final assessment of the functionality and utility of the system. Assuming this determination is positive and that sufficient benefit is achieved, Caltrans may then consider deploying the system at additional locations, such as U.S. 50 near Echo Summit and Interstate 5 near the Grapevine.

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APPENDIX A:
KINGVALE BASE STATION OPUS SOLUTION

```
FILE: 5225K50229201211060000B.12O OP1352239191810

 1008   NOTE:  Antenna offsets supplied by the user were zero. Coordinates
 1008   returned will be for the antenna reference point (ARP).
 1008
 2005   NOTE:  The IGS precise and IGS rapid orbits were not available
 2005   at processing time. The IGS ultra-rapid orbit was/will be used to
 2005   process the data.
 2005
                            NGS OPUS SOLUTION REPORT
                            ========================

All computed coordinate accuracies are listed as peak-to-peak values.
For additional information: http://www.ngs.noaa.gov/OPUS/about.jsp#accuracy

      USER: bryan.newstrom@mts.com                  DATE: November 07, 2012
RINEX FILE: 52253110.12o                            TIME: 00:01:49 UTC


  SOFTWARE: page5  1209.04 master53.pl 082112      START: 2012/11/06  00:00:00
 EPHEMERIS: igu17132.eph [ultra-rapid]              STOP: 2012/11/06  22:14:30
  NAV FILE: brdc3110.12n                       OBS USED: 55883 / 57812   :  97%
  ANT NAME: TRM57971.00     NONE             # FIXED AMB:   205 /   223   :  92%
ARP HEIGHT: 0.00                             OVERALL RMS: 0.012(m)


 REF FRAME: NAD_83(2011)(EPOCH:2010.0000)              IGS08 (EPOCH:2012.8482)

         X:     -2503896.398(m)   0.007(m)          -2503897.238(m)   0.007(m)
         Y:     -4261341.257(m)   0.003(m)          -4261339.975(m)   0.003(m)
         Z:      4020779.485(m)   0.012(m)           4020779.460(m)   0.012(m)

       LAT:   39 19  1.51326      0.008(m)        39 19  1.52659      0.008(m)
     E LON:  239 33 43.85485      0.008(m)       239 33 43.79753      0.008(m)
     W LON:  120 26 16.14515      0.008(m)       120 26 16.20247      0.008(m)
    EL HGT:         1840.878(m)   0.008(m)              1840.336(m)   0.008(m)
 ORTHO HGT:         1864.313(m)   0.026(m) [NAVD88 (Computed using GEOID12A)]

                       UTM COORDINATES    STATE PLANE COORDINATES
                        UTM (Zone 10)         SPC (0402 CA 2)
Northing (Y) [meters]     4355095.479           684364.422
Easting (X)  [meters]      720884.829          2134703.091
Convergence  [degrees]     1.62408400           0.98490622
Point Scale                1.00020077           0.99992287
Combined Factor            0.99991198           0.99963416

US NATIONAL GRID DESIGNATOR: 10SGJ2088455095(NAD 83)


                              BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
DE6252 ZOLE ZOLEZZI COOP CORS ARP          N392517.999 W1194512.036   60132.6
DH8860 DOT1 CARSON CITY COOP CORS ARP      N390922.300 W1194548.330   60920.0
AF9564 QUIN QUINCY CORS ARP                N395828.380 W1205639.889   84988.1

                 NEAREST NGS PUBLISHED CONTROL POINT
KS0092      L 1201                         N391859. W1202538. 915.9

This position and the above vector components were computed without any
```


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knowledge by the National Geodetic Survey regarding the equipment or field operating procedures used.

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APPENDIX B: DRIVER ASSISTANCE SYSTEM DESIGN DETAILS, SETUP, AND OPERATIONS MANUAL

Provided by Craig Shankwitz and Bryan Newstrom, MTS Systems Corporation
November, 2012

System Overview

The HUD (Head-Up Display) is designed to assist drivers by projecting visual information into the forward-looking field of view. A perspective projection image of the lane boundaries that is the same as what drivers expect to see is displayed in order to minimize the driver's mental workload in recognizing the presented visual information. The driver sees through the combiner which displays an image generated by the computer and superimposed on the real outdoor scenery. The optics are designed such that the image is projected approximately 30 – 39 feet (9 – 12 m) in front of the vehicle to minimize the need to re-focus the eyes between the cab interior and the outside environment. The perspective projection of the lane boundaries is programmed so that they match the real road boundaries, with the shape of the image continuously updated as the vehicle moves. The objective is for drivers to perceive the projected lane boundaries as real when the actual road boundaries are occluded, and thus facilitate the driver's ability to keep the vehicle within the driving lane. If the driver were to leave their lane the system will warn the driver. The system will change the color of the lane boundary the vehicle is crossing to red and rumble the same side of the seat.

To avoid collisions, the system uses radar to determine the presence and location of potential obstacles on the roadway. The obstacles are presented in the HUD as a rectangle; the obstacles are presented at their correct azimuth angle, and sized according to their distance from the vehicle (the closer they are, the larger the rectangle appears). If an obstacle is closer than 75 feet (23 m) to the front of the vehicle, it is shown in red (as a warning). If an obstacle is greater than 75 feet (23 m) from the vehicle, it is shown in white (as an advisory).

External system components (GPS antenna, radar antenna, and cellular modem antenna (for GPS corrections)) are shown in Figure B.1; the HUD components are shown in Figure B.2.

Driver Interface: Head-Up Display

The HUD consists of three components: the image source, the combiner, and the "sunglasses" visor. Each component is described below.

Combiner - "Combines" the actual road with the computer generated road. The driver can see through the combiner and also see a reflection of the image presented by the image source.
The combiner is made from a heat-formed acrylic, and treated with a reflective coating on the concave side, and an anti-reflective coating on the convex side. **It is important to note that these coatings are relatively delicate, and cannot tolerate any sort of chemical cleaner (Windex, Sparkle, etc.) or any sort of rubbing**. The cleaning process is described below.

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Figure B.1: System components mounted on the outside of the vehicles

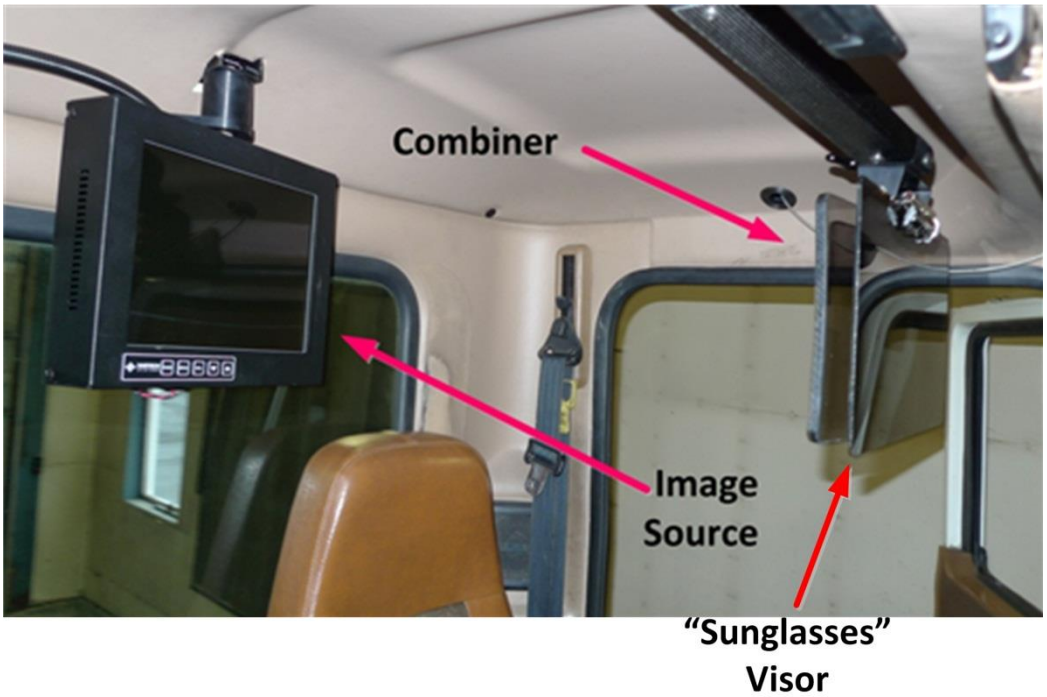

Figure B.2: Head-Up Display components

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Cleaning Process

- **Simple Cleaning.** Dust is the primary dirt source in Kingvale. If the combiner becomes excessively dusty, the combiner can be blown off with compressed, dry air.
- **Thorough Cleaning.** To thoroughly clean the combiner, the combiner can be removed from the carbon fiber arm by removing the carriage bolt held on by the knob. Once removed, the combiner can be run under water to remove the dirt. The combiner can be dried by using compressed, dry air to blow the water off of the combiner.

  If finger prints are an issue, the finger prints can be removed by using isopropyl alcohol and a soft, clean cloth. **DO NOT RUB THE COMBINER with the soft cloth!!** Instead, just tamp the combiner with the alcohol-wetted cloth to remove the fingerprints.

  Once the finger prints have been lifted, the combiner can be rinsed off with water, and blown dry with compressed, dry air.

Image Source: – Generates the image which is seen by the driver when looking through the combiner. The display has a brightness control used to allow the system to be bright during high ambient light conditions, and very dim during nighttime operation when stray light in the cab is undesirable. The brightness control is shown in Figure B.3.

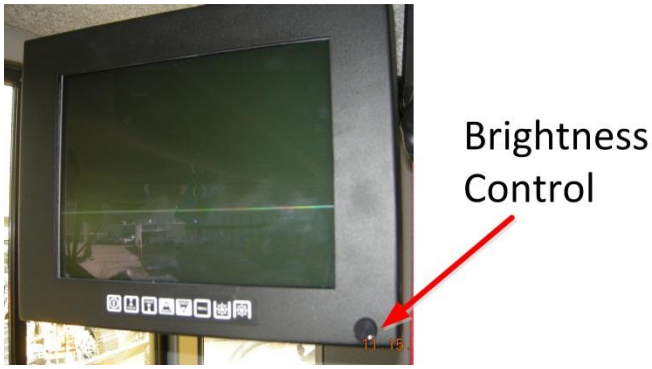

Figure B.3: Brightness control for HUD image source

"Sunglasses" visor. Because the combiner is optimized for nighttime operation, it allows a relatively large amount of light to pass through, enabling the driver to see through it even in low light conditions. However, during daylight (and especially sunny conditions), the amount of light which passes through the combiner washes out the image source. To facilitate operation in sunny conditions, the "sunglasses" visor blocks incoming light, which effectively brightens the image in the combiner.

The "sunglasses" visor should be cleaned in the same manner as the combiner, with care taken not to rub the surface. The "sunglasses" visor is much less expensive than the combiner, and should it be broken, a number of spares have been left in the supervisor's office in the Kingvale barn.

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System On / Off Switch

All three vehicles have a manual ON/OFF switch, as shown in Figure B.4. On the plow trucks (0530506 and 7000024), the switch is mounted on the plow control panel beneath the Muncie Spreader Controls. On the Wausau blower (7005039), the ON/OFF switch is mounted on the right side of the main Wausau LCD virtual instrument display.

When the system is "ON," the amber light on the switch lights up.

Figure B.4: Driver Assist System (DAS) ON/OFF switch for plow 0530506 located beneath the Muncie spreader controls

User Interface

The user interfaced consists of two parts: the seat controller, and the Crystalfontz LCD touchpad. Both are shown in Figure B.5 and are described below.

Figure B.5: DAS user interface. The Crystalfontz LCD touchpad is on the left, and the seat controller is on the right.

<u>LCD User Interface</u>

The LCD user interface is shown below in Figure B.6. It provides status information, allows the driver to change the view in the HUD, and allows the driver to offset the location of the virtual lane to facilitate warning-free plowing over the centerline (either left or right depending on the lane) and the shoulder (or other areas where the operator need not be in the center of the lane).

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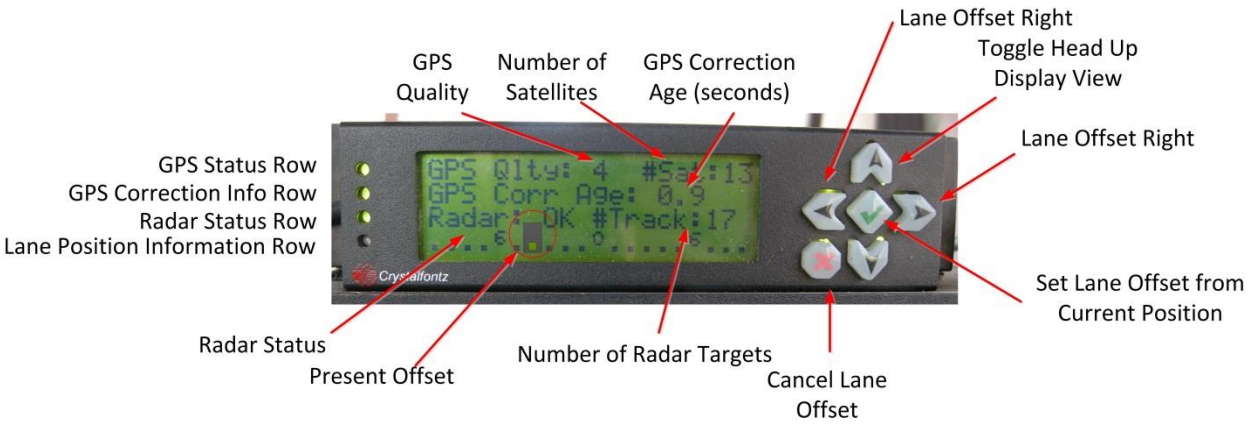

Figure B.6: DAS LCD control panel. Display shows status, and the buttons allow the driver to change the desired location of the virtual lane boundary to facilitate the plowing of shoulders or clearing over the centerline.

Seat Controller

The seat controller allows a driver to both change the intensity of the seat vibration and to turn the seat controller completely off. The switch turns the system on/off, and the intensity of the vibration is changed by the knob on the controller box. The seat controller is shown below in Figure B.7.

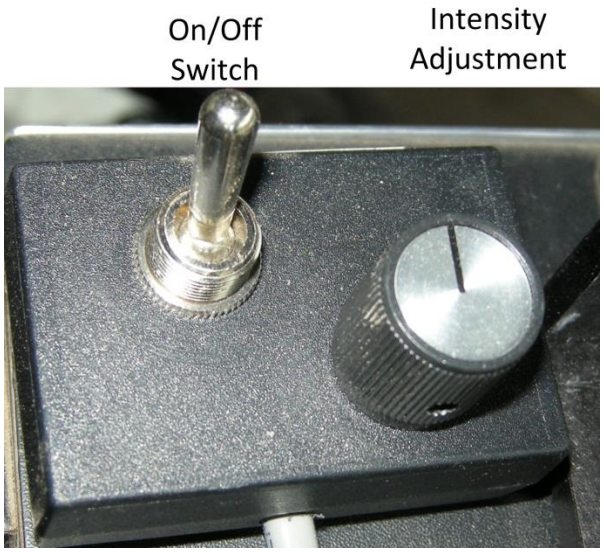

Figure B.7: Seat controller showing seat switch and intensity adjustment

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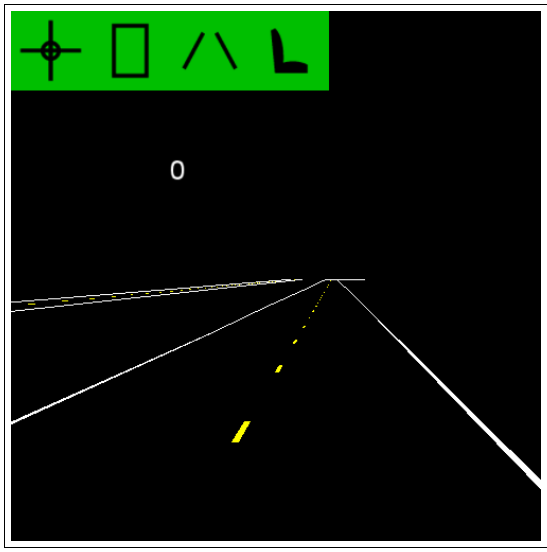
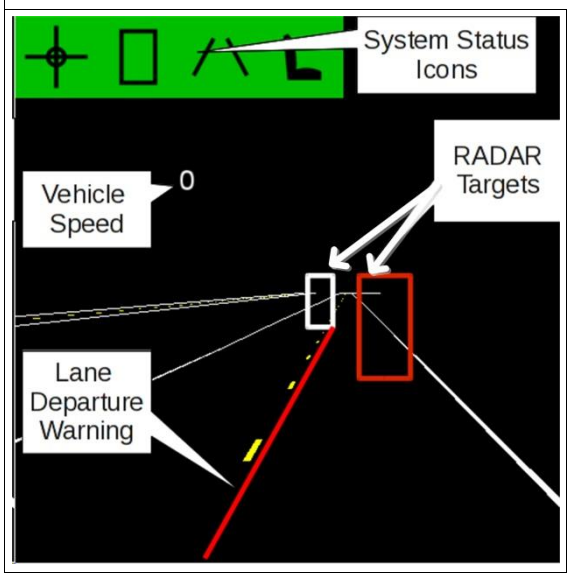
Typical Views through the HUD

	This image represents the typical computer generated view seen thought the HUD. In this view the driver can see two lanes of traffic in their direction, separated by a yellow skip line and delineated by white fog lines. More traffic lanes can be seen across the median.

Lane departure warnings are shown in the HUD by changing the color of the lane marking. Radar targets are shown using white or red boxes. The vehicle speed is shown in the upper left.	
	Here the different components of the HUD are highlighted. The components are: • System status icons for GPS, radar, and lane departure warning feedback modes • Radar targets, both advisory and warning • Lane departure warning • Vehicle speed

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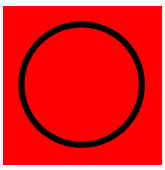
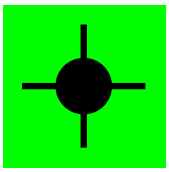
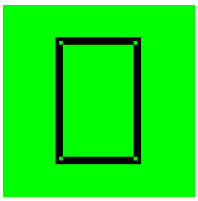
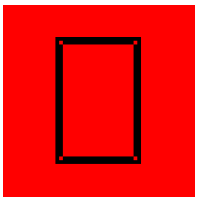
HUD Status Icons

GPS Status and Position Accuracy

	⅄ GPS Does not have a position ⅄ Lane guidance is DISABLED ⅄ GPS Quality ZERO (0)
	⅄ GPS has a position with no aiding or correction source ⅄ Worst accuracy (10 meters) ⅄ Lane guidance is DISABLED ⅄ GPS Quality ONE (1)
	⅄ GPS has position with correction source ⅄ Better accuracy (1 meter, DGPS) ⅄ Lane guidance is DISABLED ⅄ GPS Quality TWO (2)
	⅄ GPS has position with correction source ⅄ Even better accuracy (20 cm, Float) ⅄ Lane guidance is ENABLED ⅄ GPS Quality THREE (3)
	⅄ GPS has position with correction source ⅄ Best accuracy (2 cm, Fixed) ⅄ Lane guidance is ENABLED ⅄ GPS Quality FOUR (4)

Radar Status

	System is receiving radar information.
	System is NOT receiving radar data. NO targets will be shown in HUD.

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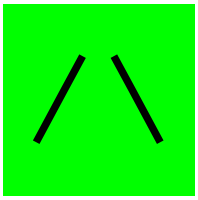
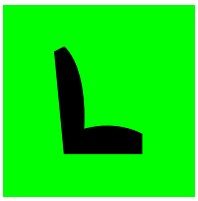
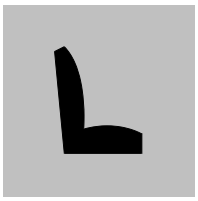
Lane Guidance Feedback Status

	Visual lane departure warnings are active.
	Visual lane departure warnings are NOT active. Causes are that the vehicle is off of a mapped road or that GPS quality is insufficient for lane guidance.
	Seat lane departure warnings are active.
	Seat lane departure warnings are NOT active Causes are that the vehicle is off of a mapped road or that GPS quality is insufficient for lane guidance.

Maintenance

With the exception of cleaning the HUD combiner and "Sunglasses" visor, no other maintenance should be required.

Power Disconnect

The DAS has only one power connection to the vehicle; if the system power is disconnected, the DAS is completely isolated from the plow and/or blower and the associated systems installed on those vehicles.

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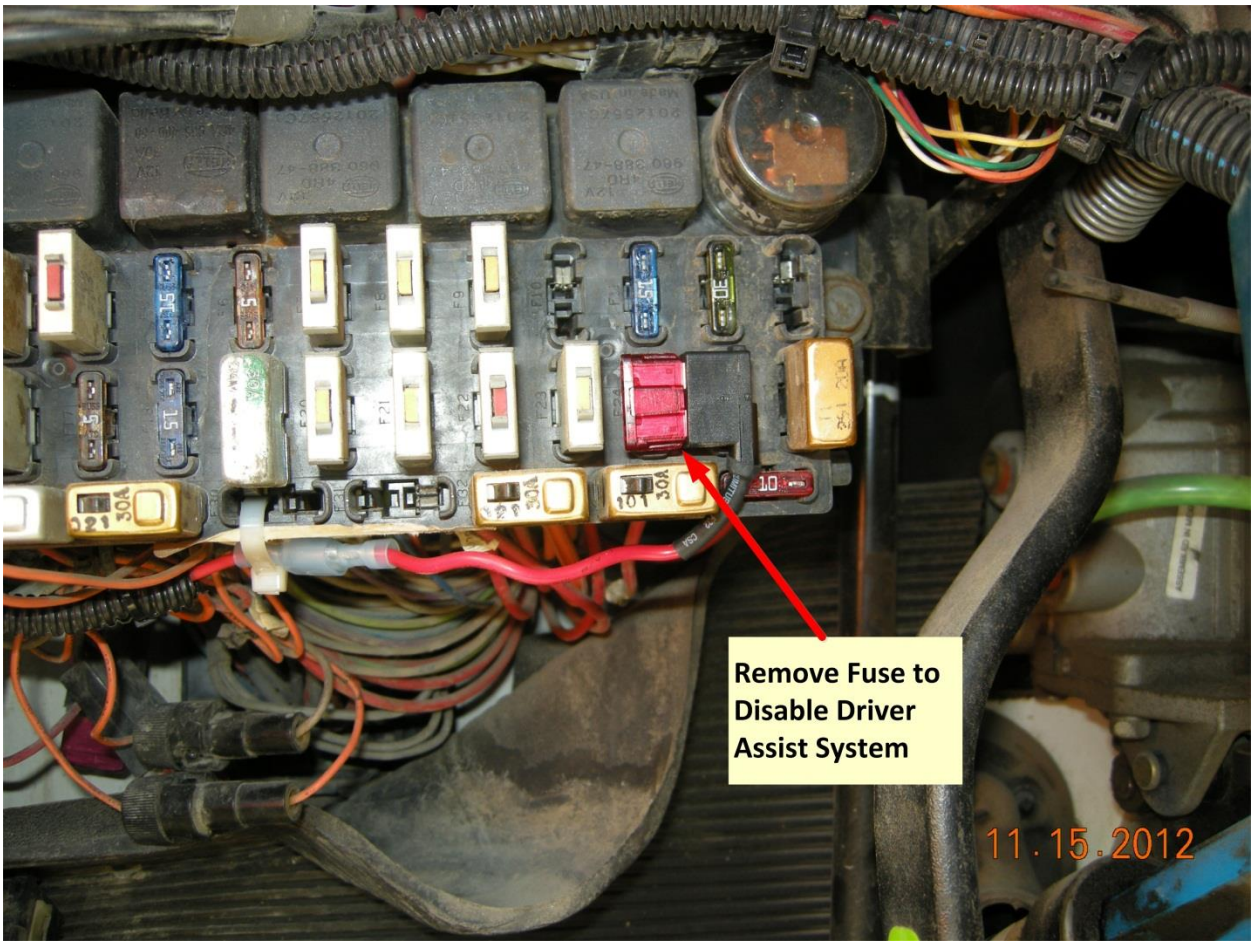

Figure B.8: DAS power connection for plow 0530506. This fuse block is located to the left of the clutch pedal in front of the driver's seat.

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Figure B.9: DAS power connection for plow 7000024. This fuse block is located behind the glove box which is in front of the passenger seat.

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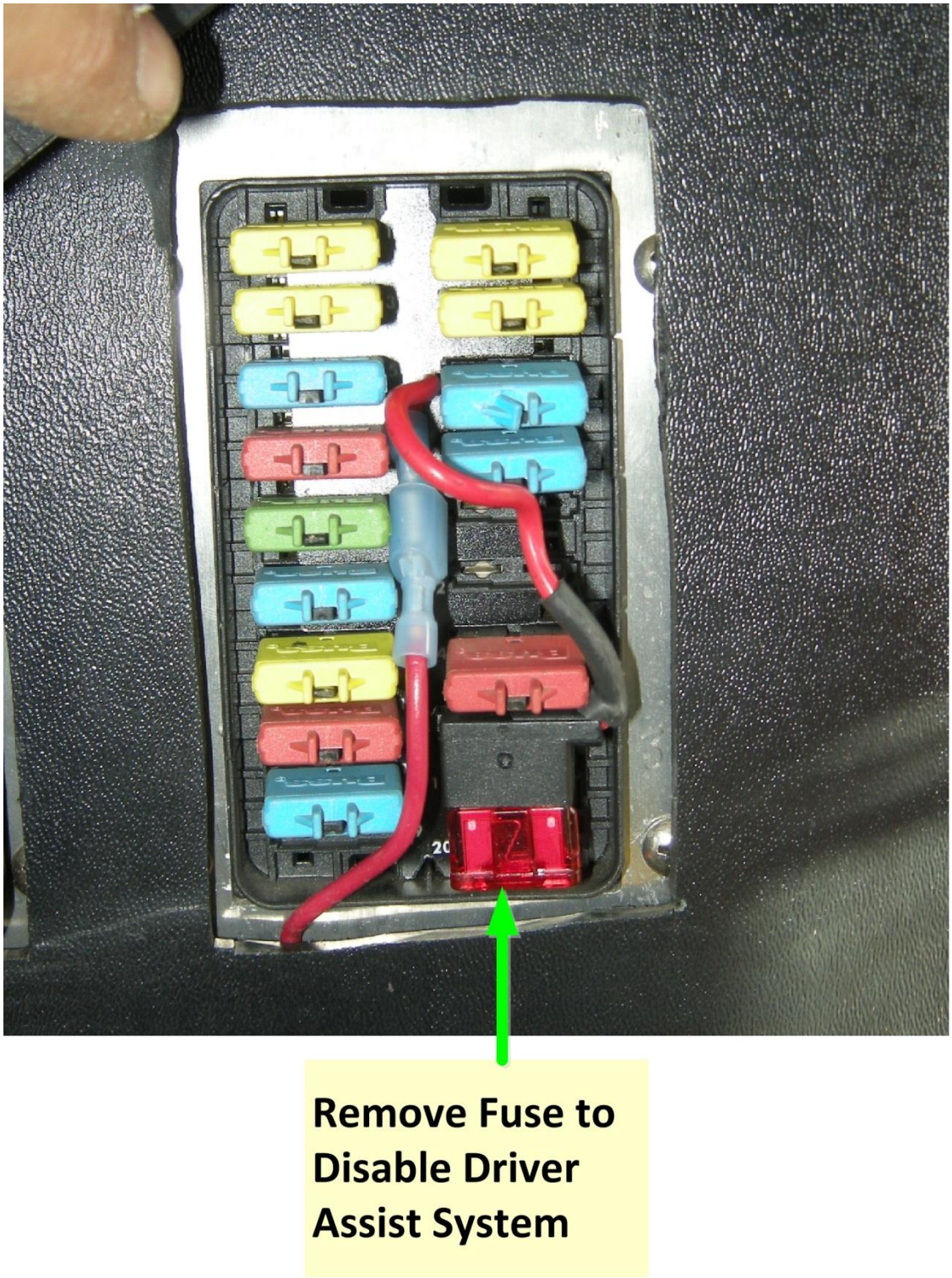

Figure B.10: DAS power connection for Wausau blower 7005039. This fuse block is located on the cable chase behind the driver's seat.

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Wiring

Wiring Common to All Vehicles.

Two wiring diagrams are common to the blower 7005039 and plows 7000024 and 0530506: the seat-to-controller wiring, and the radar-to-computer, seat controller-to-computer, and power bus-to-computer wiring. These diagrams are shown in Figures B.11 and B.12.

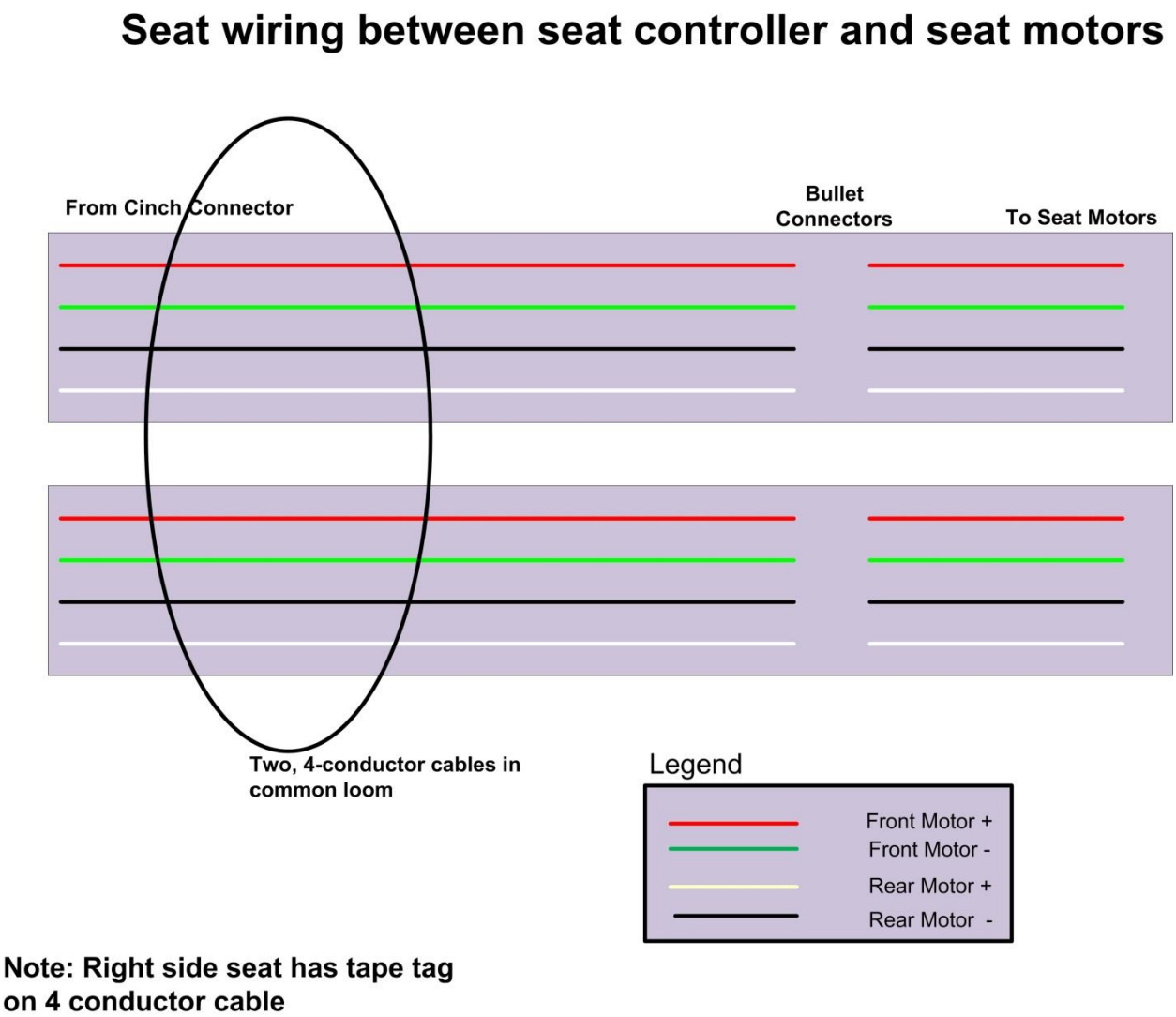

Figure B.11: Wiring between seat actuators and seat controller Cinch connector

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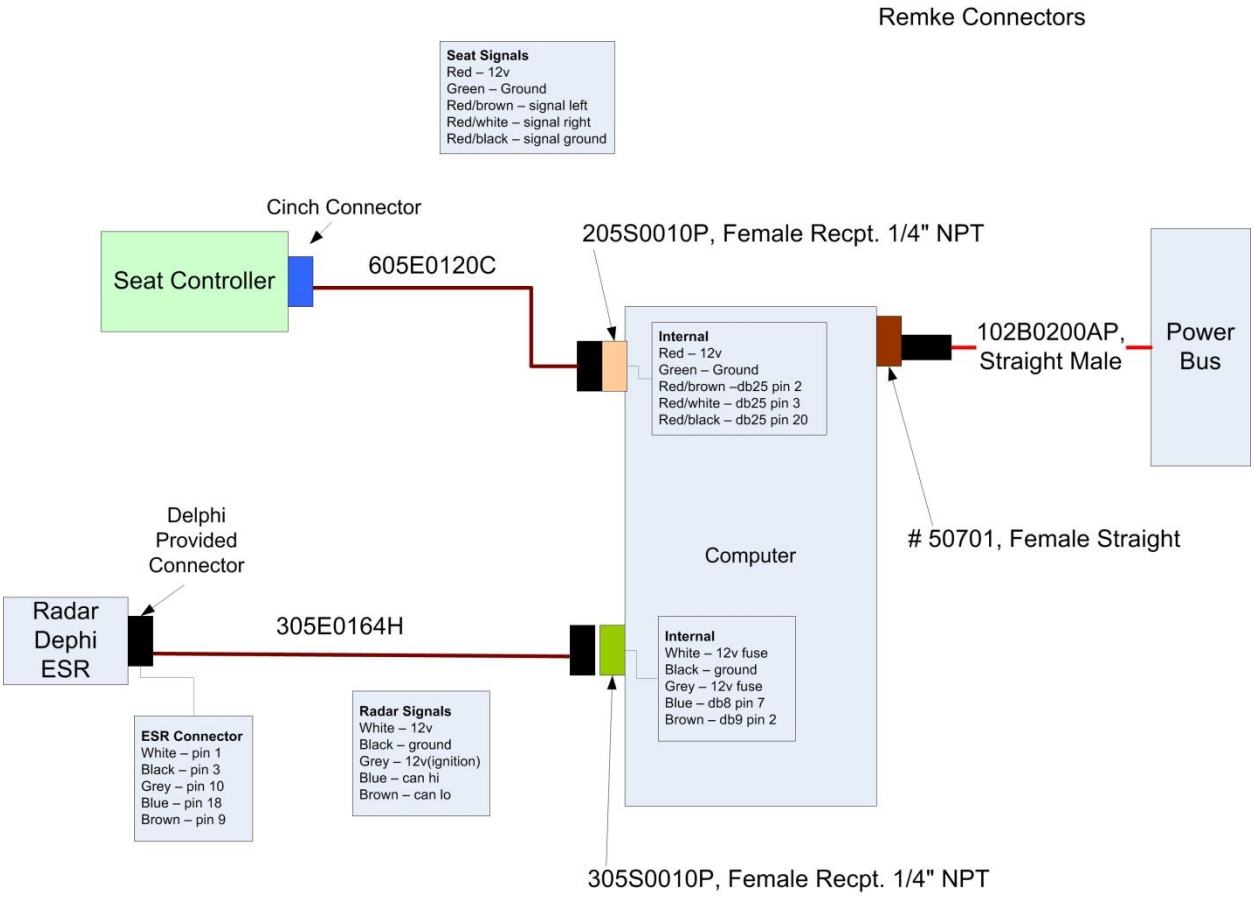

Figure B.12: Remke cabling for radar, seat controller, and computer power for all three vehicles (plows 0530506 and 7000024, and blower 7005039)

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Wiring Specific to Plow 0530506

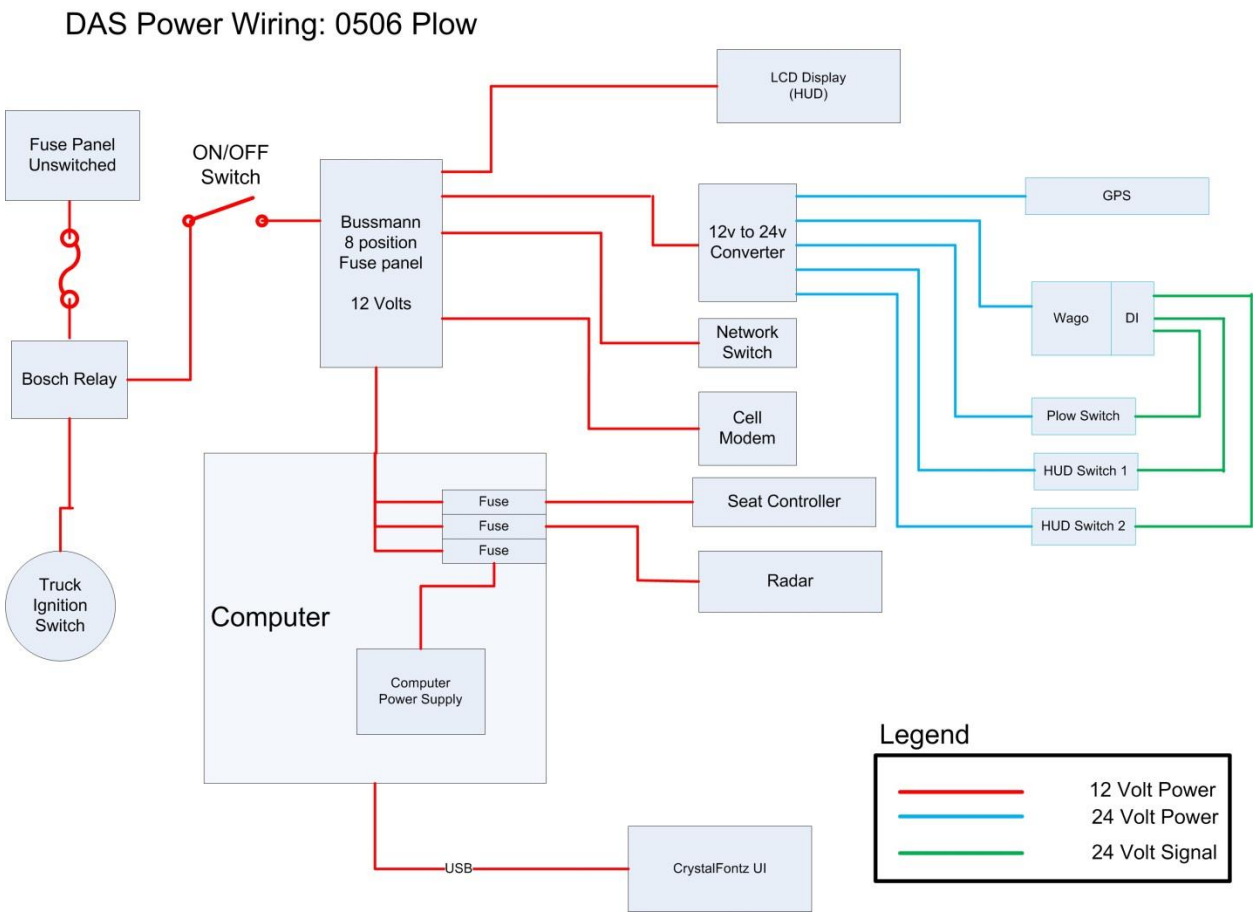

Figure B.13: Power wiring diagram for plow 0530506. The plow switch is used by AHMCT to determine how often the DAS is used while plowing snow.

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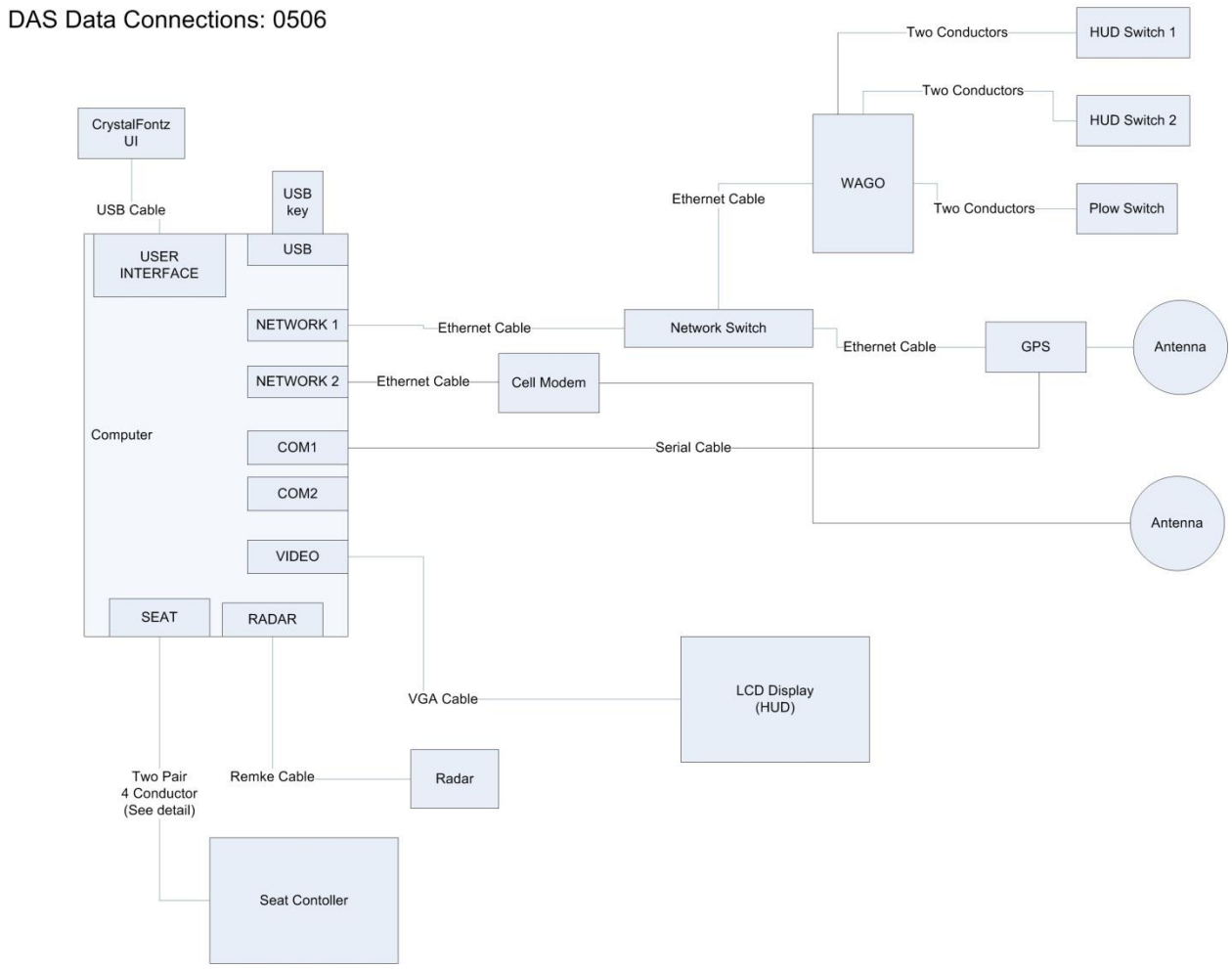

Figure B.14: Data wiring for plow 0530506. This vehicle has two HUD switches. GPS data is transferred via serial communications.

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Wiring Specific to Plow 7000024

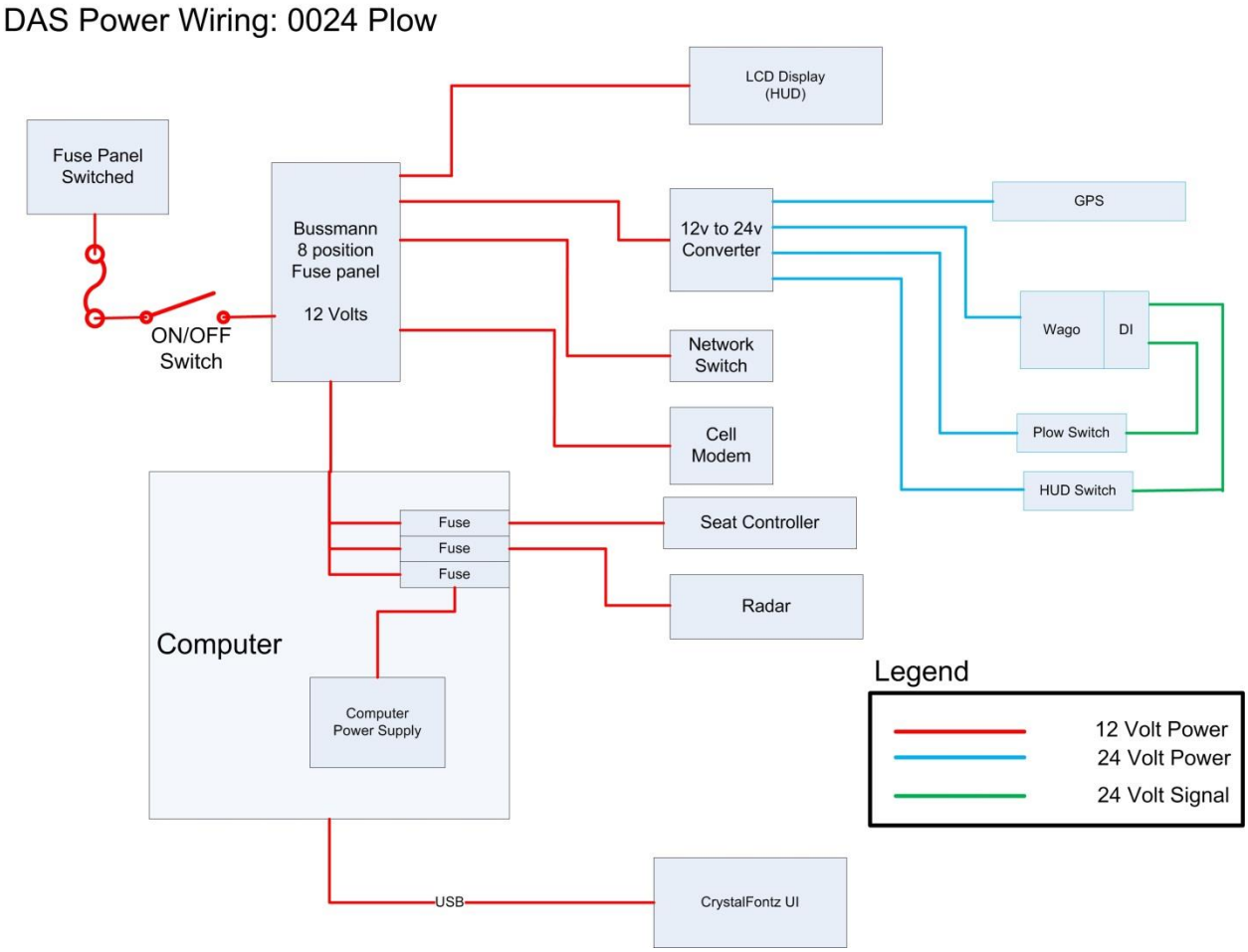

Figure B.15: Power wiring diagram for plow 7000024. The plow switch is used by AHMCT to determine how often the DAS is used while plowing snow.

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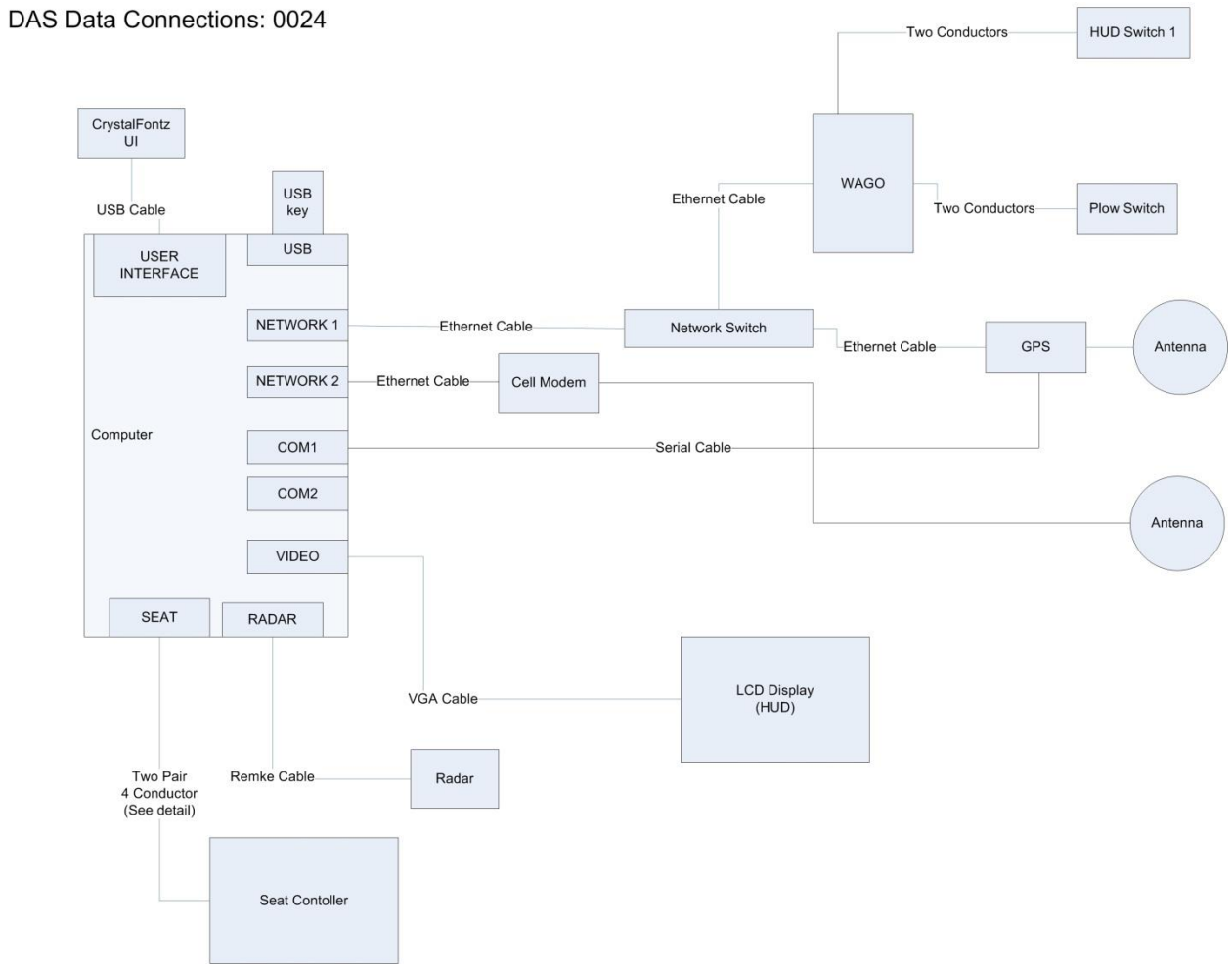

Figure B.16: Data wiring for plow 7000024. This vehicle has one HUD switch. GPS data is transferred via serial communications.

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Wiring Specific to Blower 7005039

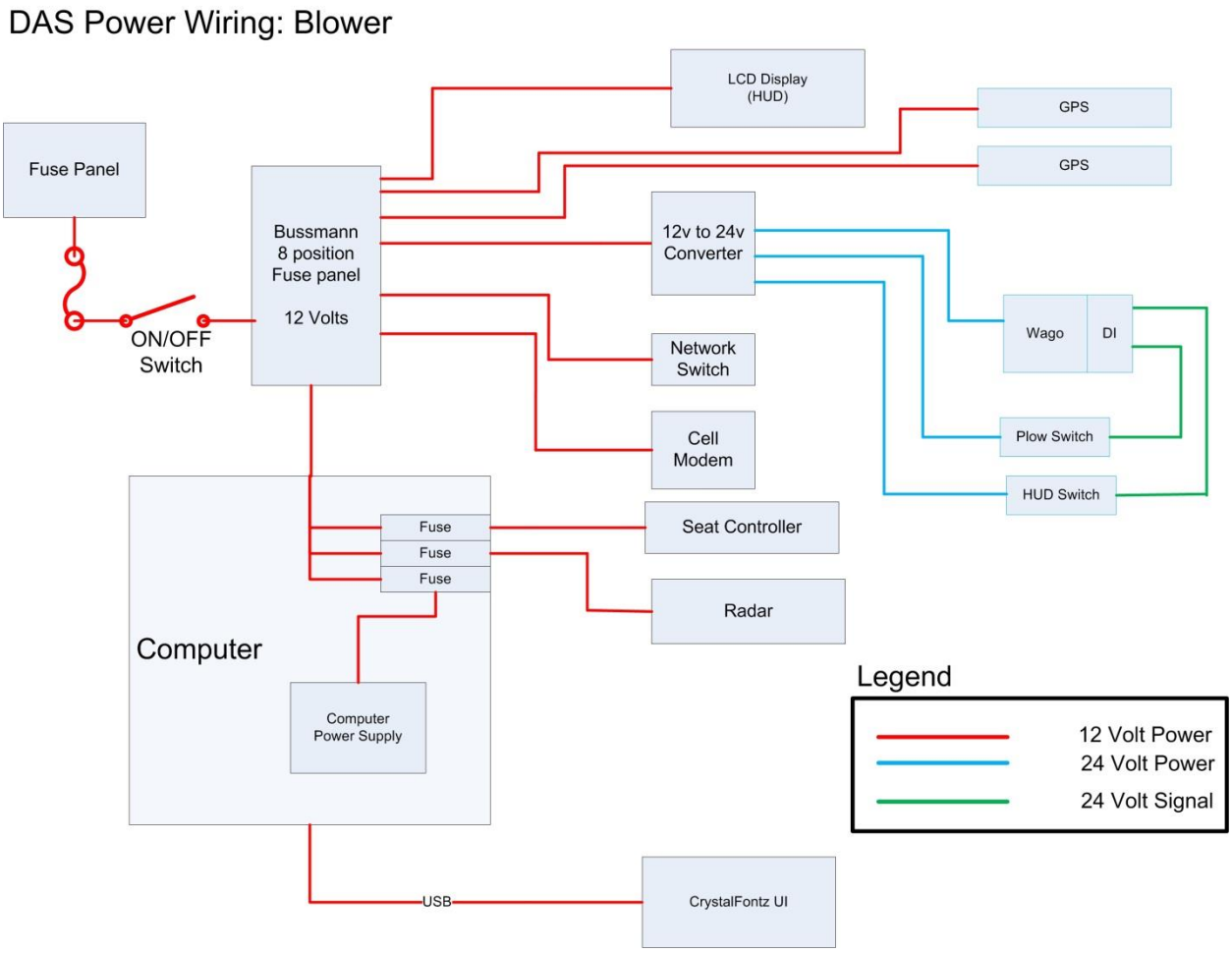

Figure B.17: Power wiring diagram for Wausau blower 7005039

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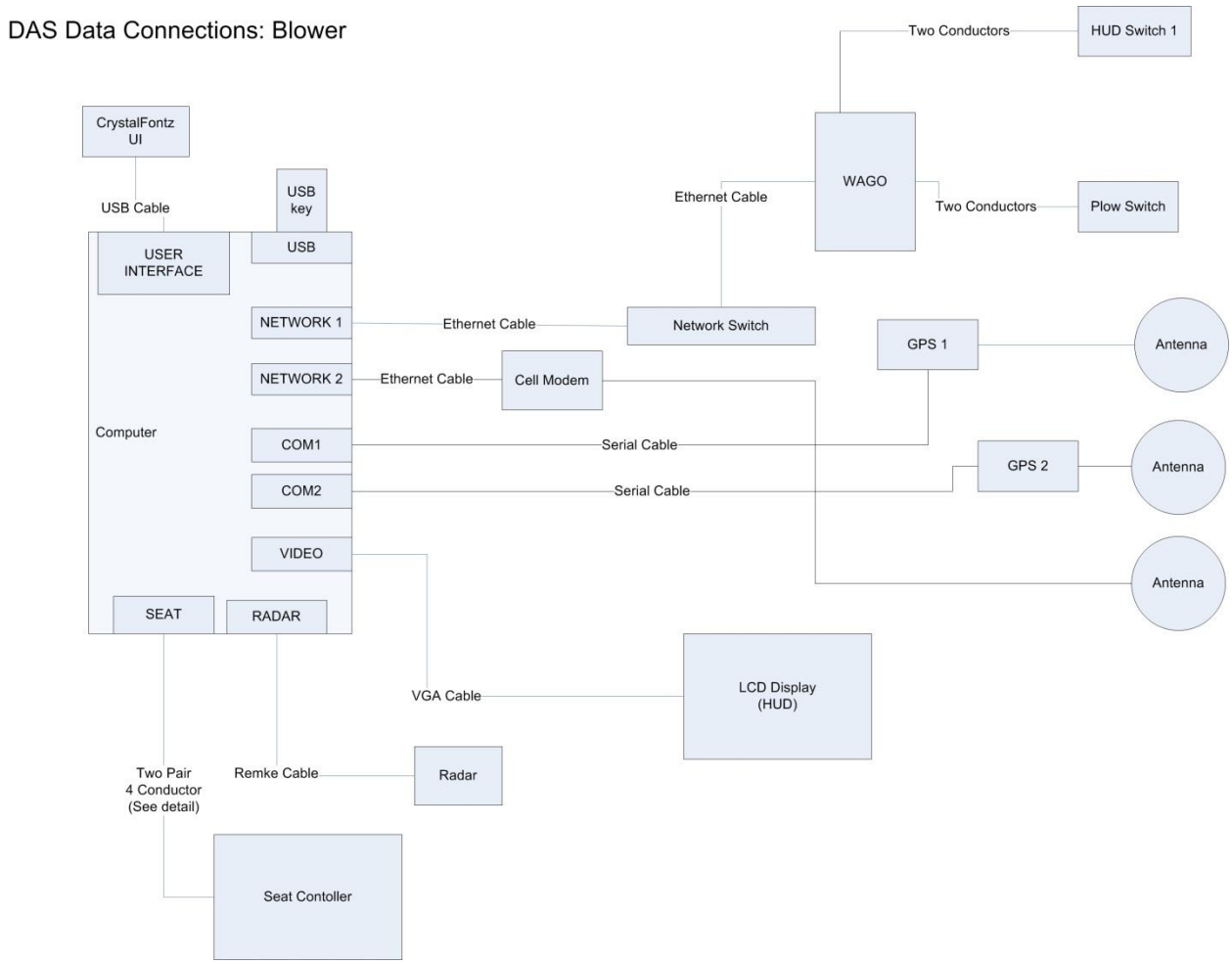

Figure B.18: Data wiring for Wausau blower 7005039. This vehicle has two GPS receivers. GPS data is transferred via serial communications.

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APPENDIX C:
DRIVER ASSISTANCE SYSTEM QUICK REFERENCE GUIDE

Provided by Craig Shankwitz and Bryan Newstrom, MTS Systems Corporation
November, 2012

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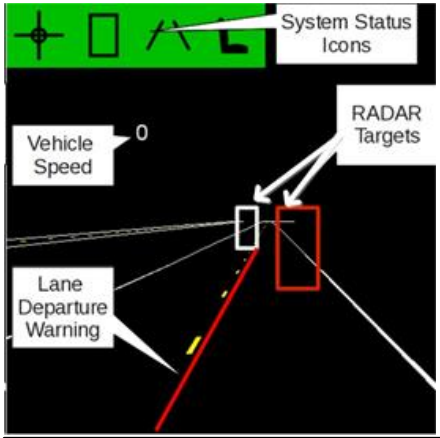
Driver Assist System Quick Reference Guide



The components are:

- System status icons for GPS, RADAR, and lane departure warning feedback modes
- RADAR targets, both advisory and warning
- Lane departure warning
- Vehicle speed

	GPS Does not have a position Lane guidance is DISABLED GPS Quality ZERO (0)
	GPS has a position with no aiding or correction source Worst accuracy (10 meters) Lane guidance is DISABLED GPS Quality ONE (1)
	GPS has position with correction source Better accuracy (1 meter, DGPS) Lane guidance is DISABLED GPS Quality TWO (2)
	GPS has position with correction source Even better accuracy (20cm, Float) Lane guidance is ENABLED GPS Quality THREE (3)
	GPS has position with correction source Best accuracy (2cm, Fixed) Lane guidance is ENABLED GPS Quality FOUR (4)

The smoked plexiglass visor should be used for sunny conditions.

	System is receiving RADAR information.
	System is NOT receiving RADAR data. NO targets will be shown in HUD.

	Visual lane departure warnings are active.
	Visual lane departure warnings are NOT active. Causes are that the vehicle is off of a mapped road or that GPS quality is insufficient for lane guidance.
	Seat lane departure warnings are active.
	Seat lane departure warnings are NOT active Causes are that the vehicle is off of a mapped road or that GPS quality is insufficient for lane guidance.

COMBINER CLEANING

DO NOT RUB COMBINER WITH ANYTHING!!!!

- **Simple Cleaning.** Dust is the primary dirt source in Kingvale. If the combiner becomes excessively dusty, the combiner can be blown off with compressed, dry air.
- **Thorough Cleaning.** To thoroughly clean the combiner, the combiner can be removed from the carbon fiber arm by removing the carriage bolt held on by the knob. Once removed, the combiner can be run under water to remove the dirt. The combiner can be dried by using compressed, dry air to blow the water off of the combiner.
  If finger prints are an issue, the finger prints can be removed by using isopropyl alcohol and a soft, clean cloth. **DO NOT RUB THE COMBINER with the soft cloth!!** Instead, just tamp the combiner with the alcohol-wetted cloth to remove the fingerprints.

  Once the finger prints have been lifted, the combiner can be rinsed off with water, and blown dry with dry compressed air.

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APPENDIX D:
DRIVER ASSISTANCE SYSTEM DATABASE FORMAT

Provided by Bryan Newstrom, MTS Systems Corporation
April, 2015

This appendix documents the required geometry and attribute data model for a DAS road database.

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Driver Assistance System (DAS)

The Driver Assistance System (DAS) is comprised of a Head-Up Display (HUD) for situational awareness and haptic feedback via the vibrating driver's. The feedback provided to the driver for each of these systems is computed using a highly accurate RTK GPS and a road database. Figure D.1 shows the components of the DAS.

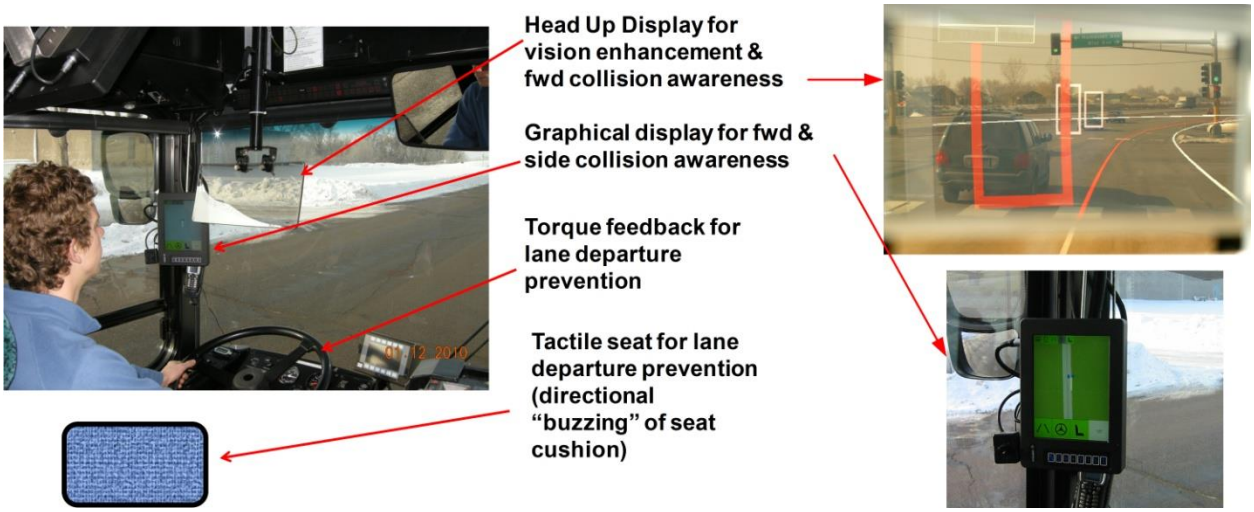

Figure D.1: Driver Assist System (DAS)

Situational Awareness

The HDD creates a computer generated image of the area around the vehicle that shows the current position on the lane, lane departure warnings, and any objects detected by the onboard radar. A HUD is a forward looking view point that conforms to and augments the forward view of the operator. The HUD typically combines a virtual view and the real view using an optical combiner that is positioned in the operator forward field of view (FOV).

To generate the view used on the HUD, the locations of the lane markings, signs and other stationary obstacles are required.

Lane Departure Warnings

To provide the operator with lane departure warnings, the DAS compares the position within the current lane and vehicle size with the lane centerline and lane width. If a point on the vehicle is farther from the centerline than half the width of the lane, a lane departure warning is generated.

Radar Filtering

To reduce the amount of data shown to the operator on the HUD, any detected radar target that is determined not to be a threat is filtered out and not shown in the display. Radar target filtering is based on the location of the detected target relative to the roadway. If the target is on the drivable surface, it is considered a threat. In this case any target detected that is in the shoulder or in the

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median of a divided highway can be filtered out. This filtering is done by knowing the location of the edge of the drivable surface. The radar targets can be further filtered by comparing which lane the target is located and the lane the vehicle is located. This allows for filtering oncoming traffic that is that is not a threat—traffic that is in the oncoming lanes.

Data Collection and Processing

To create a map database that accurately matches the real-world geometry it is important to collect data at a high rate and best horizontal accuracy. The preferred data rate is 10 Hz and it is preferred to only use real-time kinematic fixed GPS solutions or post processed centimeter accurate data. This data density and accuracy should be maintained throughout the map creation process. Also, any geometric object should be left as large as possible, or cut into separate pieces only when a change in attributes is warranted. For example, lane centerline geometry should be continuous for the entire length of the lane within the mapped area.

Final Data Processing

As a last step, an MTS automated tool is used to optimize the map database for real-time use with the DAS. Optimizations include reducing the point density based on geometry and tiling the database into distinct sections. The required data input format is Esri shapefiles in a local Cartesian coordinate system with units in meters, preferably using a state plane coordinate system.

Also, optimized static scenery for the HUD is generated from the database and saved in a scene graph file[6]. The scene graph file contains the static object data (points, lines, and colors) to be drawn by the HUD. This is also an optimization for real-time use.

The result of this final processing is then installed on the DAS computer.

Data Model

The required road information for the DAS has been formulated into a simple data model. A visual representation of the data model is shown in Figure D.2. Each of the components is described below.

[6] https://en.wikipedia.org/wiki/Scene_graph

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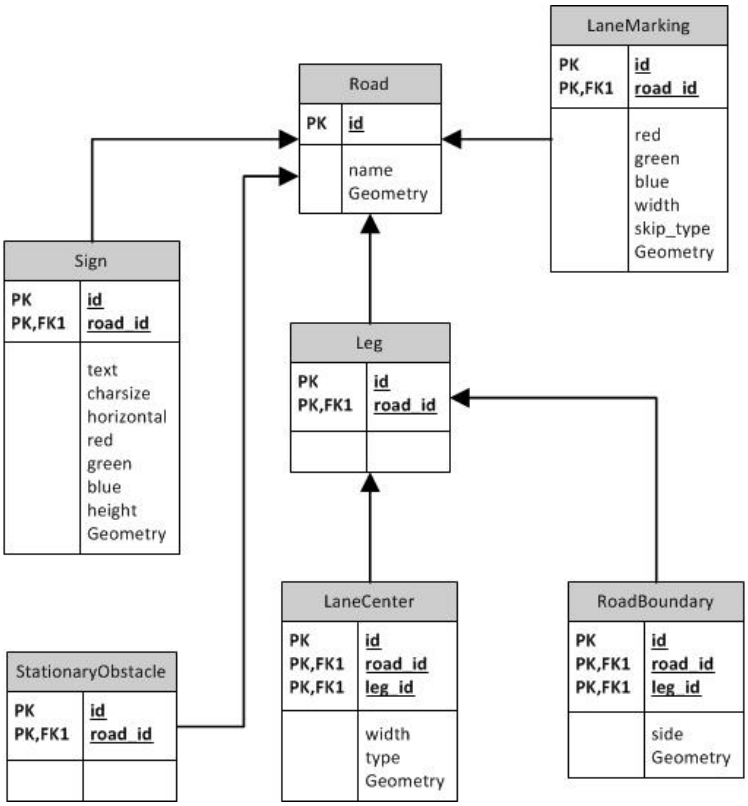

Figure D.2: DAS Data Model with entity relationships and attributes. PK is primary key; FK1 is foreign key (a primary key from another entity). Together the primary key and the foreign keys uniquely identify the object with the database.

Geometry

The geometry used for the data is either a point or a series of points (LineString). The geometry is defined in a Cartesian coordinate system with units of meters. Historically, a state plane coordinate system has been used.

Point

A two- or three-dimensional (2D, 3D) location. This is usually a single GPS fix or an averaging of multiple GPS fixes. Height data is not be used within the DAS.

LineString

A series of points in a defined order. The order of the points defines the direction of the LineString. For a LaneCenter, the LineString order defines the direction of travel for the lane.

Road

A Road is the top-level data object. All other objects must reference a Road. A Road can contain geometry, but the geometry is not used.

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Attribute	Type	Description
Id	Integer, Primary Key	Identifier for Road
Name	String	Name of Road
Geometry	LineString	Optional center line of Road

Leg

A Road is typically split into two Legs that reflect the two directions of travel for the road, e.g. eastbound and westbound I-80. A Leg does not contain geometry.

Attribute	Type	Description
Id	Integer, Primary Key	Identifier(number) for Leg
Road Id	Integer, Foreign Key	Id of parent Road

LaneCenter

A LaneCenter is the LineString geometry representing the center of a single lane of traffic. A Road Leg contains one or more LaneCenters. LaneCenters are used by the DAS to compute lane departure warnings. For the HUD, a lane departure warning is shown by a red line that is the LaneCenter offset by half the lane width toward the side corresponding to the lane departure warning.

Attribute	Type	Description
Id	Integer, Primary Key	Identifier for LaneCenter
Road Id	Integer, Foreign Key	Id of parent Road
Leg id	Integer, Foreign Key	Id of parent Leg
Width	Real	Lane width in meters
Type	String	“traffic”, “turn”, or “shoulder”
Geometry	LineString	

RoadBoundary

A RoadBoundary is a LineString representing the boundary between the drivable and non-drivable surface of a Road. A RoadBoundary can be thought of as the extents of the road, or all the lanes and Legs of a Road which are within the RoadBoundaries. RoadBoundaries are used to determine if a radar target is on the drivable surface.

Attribute	Type	Description
Id	Integer, Primary Key	Identifier for RoadBoundary
Road Id	Integer, Foreign Key	Id of parent Road
Leg id	Integer, Foreign Key	Id of parent Leg
Side	Integer	Determines with location of the lanes relative to the geometry (-1 for left, 1 for right)
Geometry	LineString	

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The Side attribute captures where the lanes are located relative to the direction of the RoadBoundary. With the direction of the RoadBoundary being forward, a Side value of -1 specifies that the lanes are to the left and a Side value of 1 means that lanes are on the right. Figure D.3 shows possible values for a RoadBoundary Side attribute.

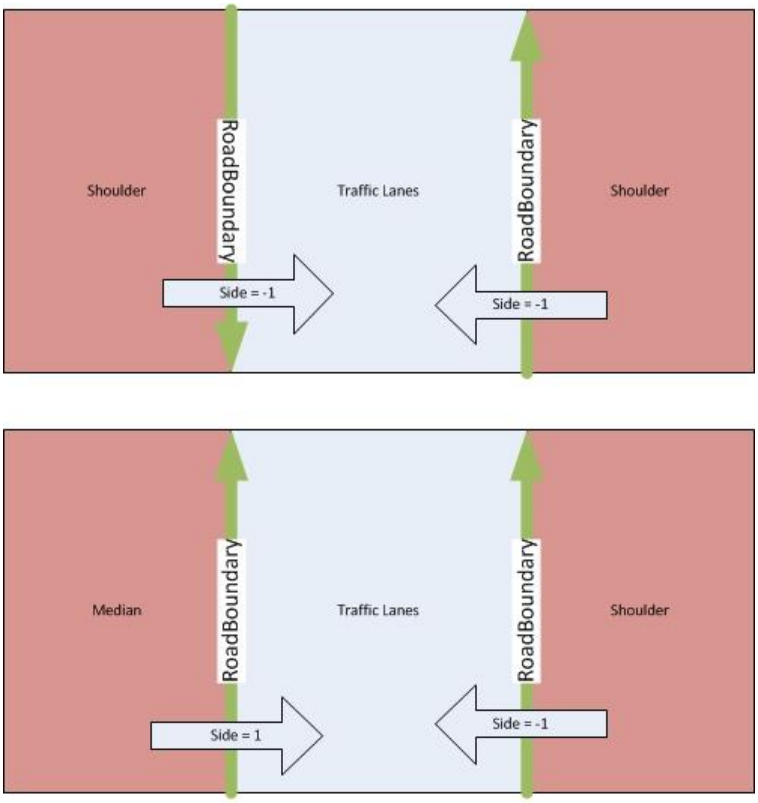

Figure D.3: RoadBoundary Side attribute

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LaneMarking

LaneMarking typically corresponds to the paint markings applied to the pavement. The LaneMarking data contains attributes on how to display the data in the DAS display. LaneMarkings are use in the HUD to intuitively show the geometry of the roads and lanes.

Attribute	Type	Description
Id	Integer, Primary Key	Identifier for LaneMarking
Road Id	Integer, Foreign Key	Id of parent Road
Red	Integer	Red component of color (0 to 255)
Blue	Integer	Blue component of color (0 to 255)
Green	Integer	Green component of color (0 to 255)
Width	Real	Width of lane marking in meters
Skip type	Integer	Type of line 1. Solid line 2. Skip line 3. Solid left, skip right 4. Skip left, solid right 5. Double solid 6. Double skip
Geometry	LineString	

The Red, Green, Blue attributes define the color of the LaneMarking in the standard RGB format, where each attribute is a number from 0 to 255. Together they defined an object's color. Examples are:

- Black = (red:0, green:0, blue:0)
- White = (red:255, green:255, blue:255)
- Red = (red:255, green:0, blue:0)
- Yellow = (red:255, green:255, blue:0)

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Signs

Signs depict real signs in the landscape. Typically Signs are used to show mile markers in the DAS displays.

Attribute	Type	Description
Id	Integer, Primary Key	Unique Identifier for sign
Road Id	Integer, Foreign Key	Id of parent Road
Text	String	Text to display
Character Size	Real	Character/Font size (implementation dependent, use 1.0)
Horizontal	Integer	Text alignment (0 = vertical, 1 = horizontal)
Red	Integer	Red component of color (0 to 255)
Green	Integer	Green component of color (0 to 255)
Blue	Integer	Blue component of color (0 to 255)
Height	Real	Height of sign post in meters
Geometry	Point	

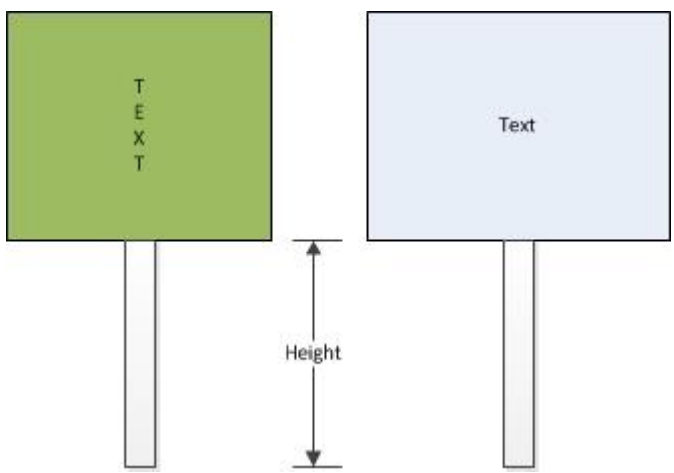

Figure D.4: Two Signs with vertical text (Horizontal = 0) on the left and horizontal text (Horizontal=1) on the right

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Stationary Obstacles

Stationary Obstacles are permanent non-point structures in the landscape. Typically they correspond to guardrails, Jersey barriers, K-rails, or bridge abutments. How these structures are shown in the HUD is defined separately from the database and generated during the final processing stages.

Attribute	Type	Description
Id	Integer, Primary Key	Identifier
Road Id	Integer, Foreign Key	Id of parent Road
Geometry	LineString	

Examples

Two-Lane Road

Figure D.5 shows data collected for a two-lane road. The arrows depict the direction of the underlying LineString. The road has two legs with opposing directions.

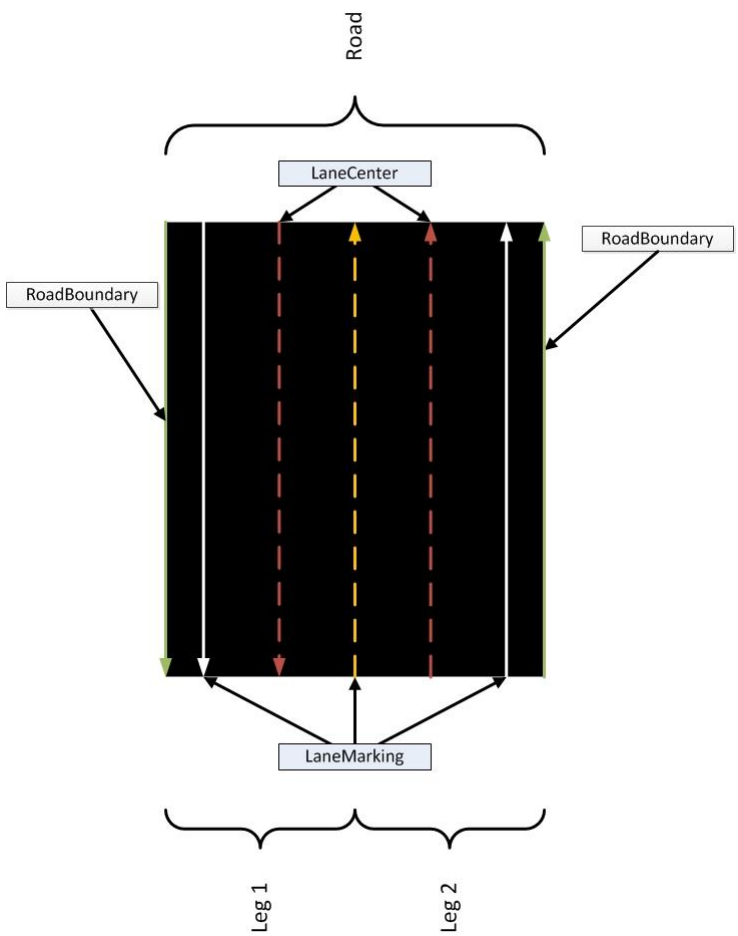

Figure D.5: Two-lane road

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Four-Lane Divided Road

Figure D.6 show the data required for a four-lane divided road. The legs of this road are separated by a median. The arrows reflect the direction of the traffic flow and the order of the points within the LineStrings.

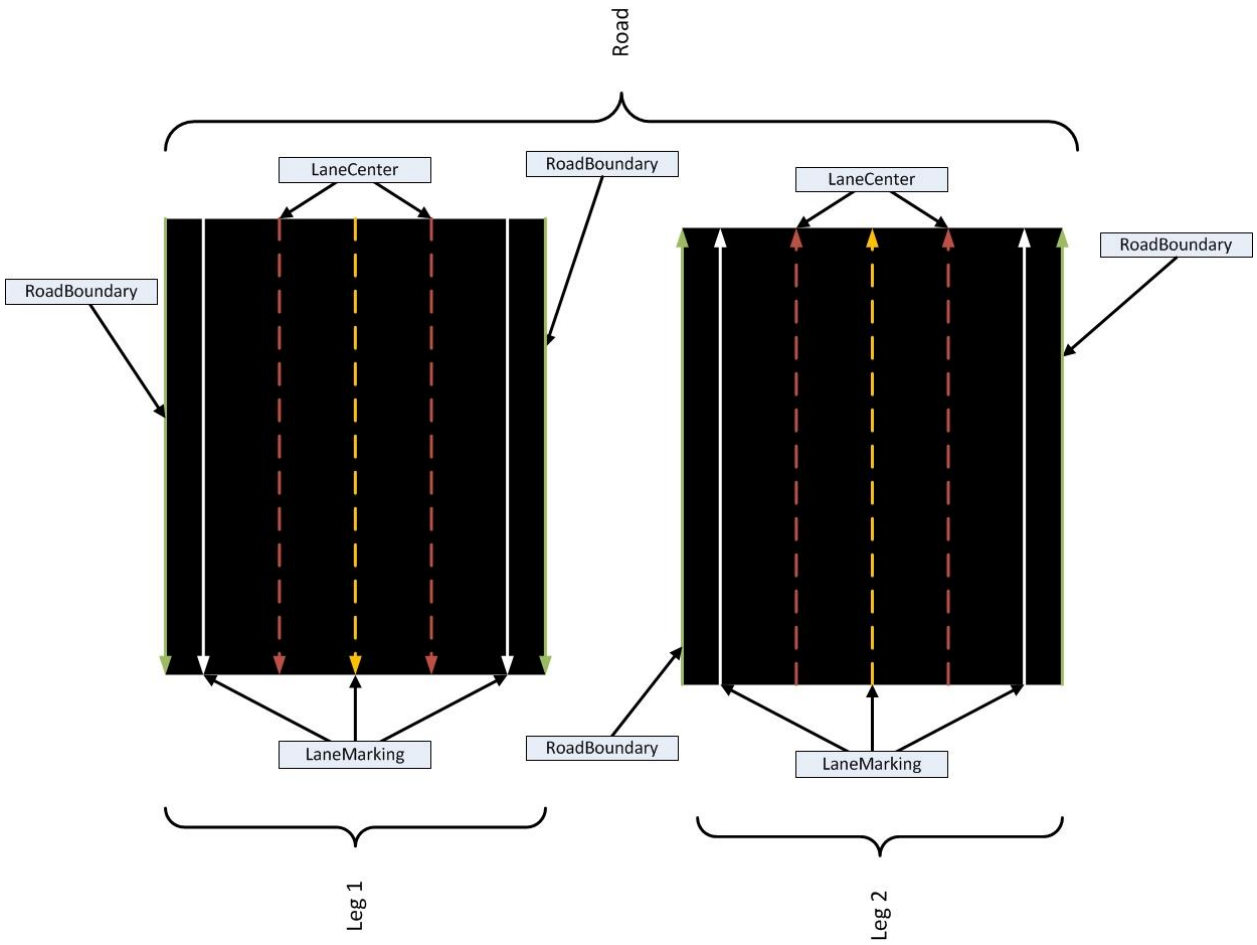

Figure D.6: Four-lane divided road

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Simple Intersection

Figure D.7 shows an intersection of 2 two-lane roads where one road has turn lanes. The LaneMarkings stop at the intersection, but the LaneCenters are continuous. In this example the turn lanes do not have LaneCenters, so the operator will not get lane departure warnings when in these lanes.

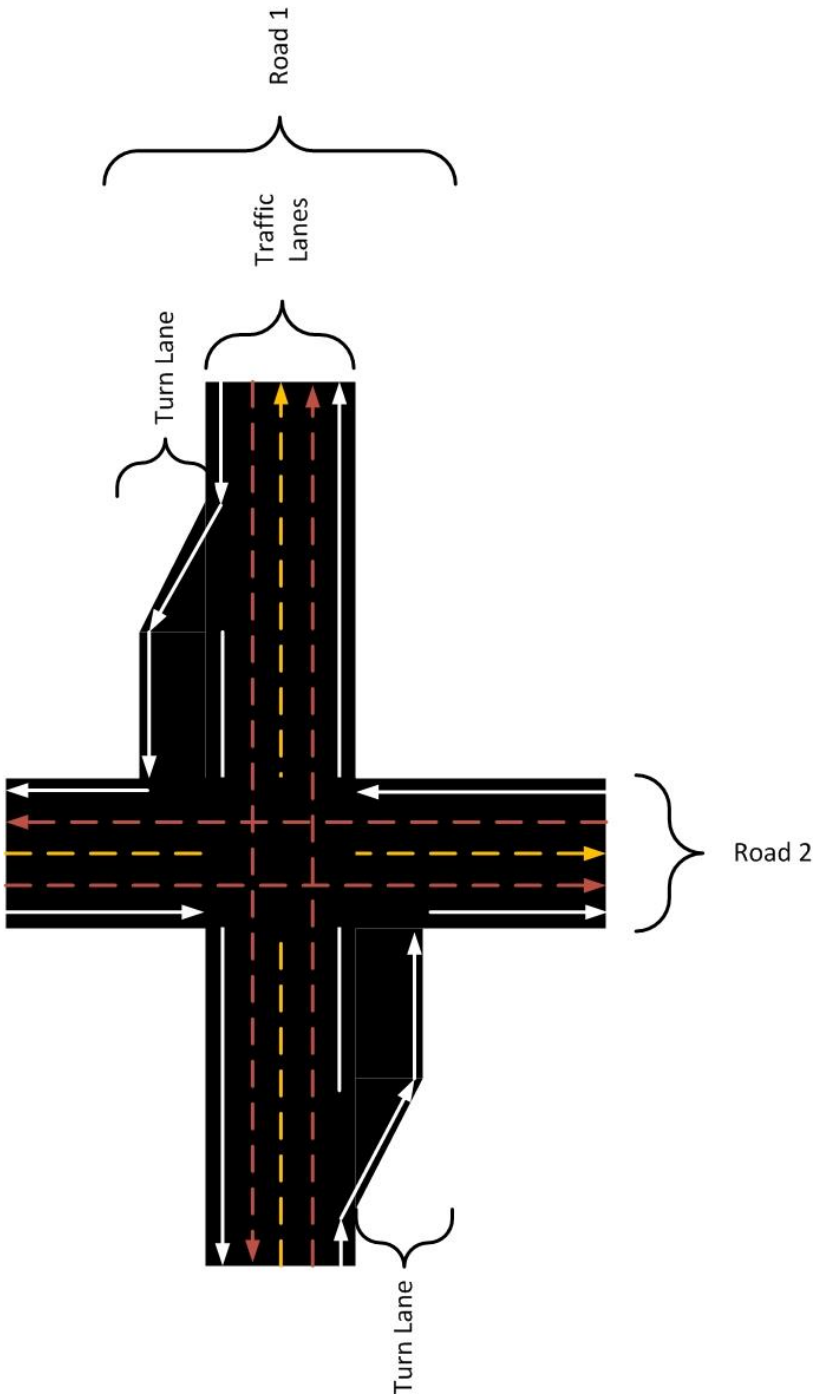

Figure D.7: An intersection of 2 two-lane roads

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Guardrails

As an example of stationary Obstacles, geometry for a simple guardrail will be defined. The 2D GPS data is collected with one point for each guardrail post, as shown in Figure D.8.

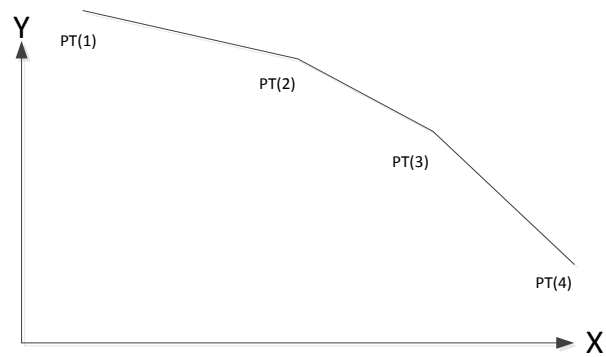

Figure D.8: Guardrail 2D location data

A simple geometry pattern and color is defined to represent each line segment of the guardrail (see Figure D.9). The pattern will be scaled in the L axis direction (along the roadway) to match the length of the line segment. The Z axis direction will be unscaled.

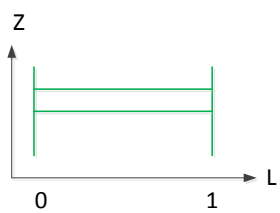

Figure D.9: Guardrail geometry pattern

The 3D object data is generated by locating and scaling the geometry pattern between every point of the guardrail, as in Figure D.10.

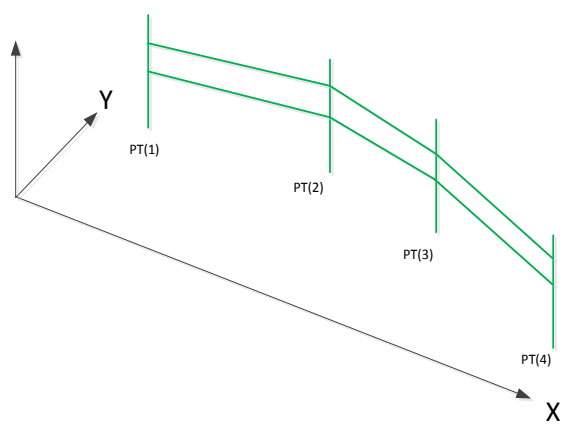

Figure D.10: Resulting guardrail 3D graphics

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APPENDIX E:
RADAR HOUSING ICING TEST BY AUTONOMUSTUFF

Provided by Josh Hartung, AutonomouStuff
March, 2013

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Radar housing icing test

Ambient temp: ~0 degC
Inconsistent but high moisture snowfall

Josh Hartung
jhartung@autonomoustuff.com
360-292-8106

03/12/2013

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Wet snow collected on the unheated radar window

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Allowing the perimeter buildup to break away

(temps were around 0C)

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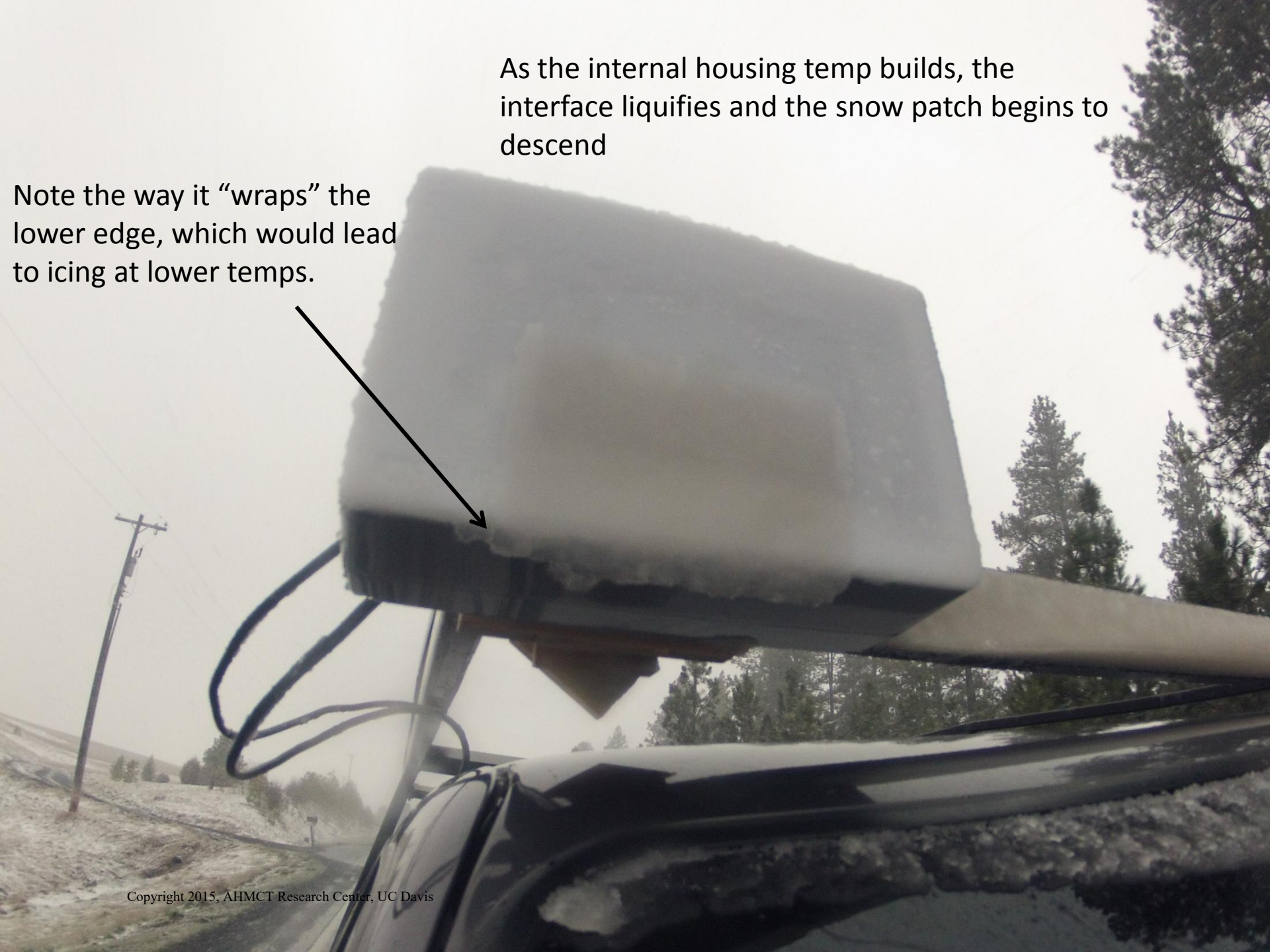
As the internal housing temp builds, the interface liquifies and the snow patch begins to descend
Note the way it “wraps” the lower edge, which would lead to icing at lower temps.
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Conclusions

- High moisture snow has exceptional ability to bridge the heated and unheated areas of the housing.
- Hard to generalize but icing likely starts with a “patch” in front of the radar which starts the bridging process.
- The radome material is exhibiting very low hydrophobicity and does not shed frozen material quickly.

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Recommendations

- Apply hydrophobic/anti-icing coating to mitigate icing patch over unheated radome.
- Increase thermoblock set temperature to increase heated area and mitigate bridging tendency.

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APPENDIX F:
GNSS BASE STATION PARTS LIST

1) Trimble NetR9 Ti-1 GNSS Reference Station with Trimble Zephyr Geodetic 2 Antenna kit: Part #: 97501-10 including:

   - 67668-10 NetR9 Ti-1 Receiver Assembly
   - 97501-99 NetR9 Accessory kit
   - 78650 PWR SUP 65W 19V 3 42A 100 240VAC
   - 78651 Power Cord kit - Cords for USA, EU, UK, Australia, with C7 Connector
   - 50150-00 Cable, 2 m, Ethernet, 10BaseT Cat 5
   - 59044 Cable - 1.5 m, DB9(F) Y to 0S/7P/M to Power Jack
   - 60154 DB9 Serial Cable
   - 11517 Cable – BNC (Bayonet Neill–Concelman) M / BNC M
   - 51010-00 Notice for Charging Battery
   - 27953 Screw (qty. 2)
   - 41124 Tripod clip
   - 50854 Resealable Baggie
   - 36451-02 Cable - 1PPS/ Event/ Power
   - 74399-00 Cable USB (Universal Serial Bus) Mini-B Plug Host to A Jack
   - 74404-00 Cable USB Mini-B Plug Host to Mini-B Plug
   - 74406-00 Cable USB Mini-B Plug Host to B Plug
   - 74408-00 Cable USB Mini-B Plug Host to A Plug
   - 58295-00 Trimble Zephyr Geodetic 2 Antenna with integrated Radome, w/ 30 m Antenna Cable

2) Sierra Wireless Raven XE V2221E-V Modem

3) Seco 2027-31 GNSS Antenna Adapter

4) Shelving kit

5) PolyPhaser 8-2.5 GHz DC Pass Protec DGXZ+15NFNF-A

6) Laird Technologies FG821/18503 - 821-896/1850-1990 MHz 5 dBi Fiberglass Omni Antenna. Laird FG821/18503 is a dual-band fiberglass omnidirectional antenna operating in the 821 – 1990 MHz frequency range. This omnidirectional antenna is unity gain in the 800 MHz band and 3 dBm gain in the 1900 MHz band. The dual-band antenna has a maximum power input of 100 watts and is terminated with an N-type female connector.

7) The FM2 mount for Laird Technologies FG821/18503

8) Wireless Solutions 10' LMR400 Jumper. Made of LMR400 with N-type male (14515) on one end and TNC (Threaded Neill–Concelman) male (RFT-1202-I): Tessco SKU: 364896 Mfg Part #: LMR400NMTNCM-10 888063648960

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APPENDIX G:
GPS DAS PARTS LIST

Computer parts:

- From www.VersaLogic.com:
    - VL-EPM-35S Leopard PC/104+ Dual-Core 2.27 GHz CPU (central processing unit)
    - VL-EPM-PS1a 50 W PC/104+ power supply
    - VL-MM7-2SBN 2 GB DDR3 (double data rate) class 2 standard temperature SDRAM (synchronous dynamic random access memory)
    - VL-F15-4EBN 4 GB eUSB drive, ET
    - VL-CBR-8006 Cable User I/0 Leopard 12”
    - VL-CBR-1201 12-pin 2 mm latch / 15-pin VGA (Video Graphics Array) cable
    - VL-CBR-1008 ATX (Advanced Technology eXtended) to EPM power adapter cable
- PCAN-PC104plus Adapter (single channel) IPEH-002094 3
- The Versa Tainer 5” with End Caps
- ESW105 ETN Unmanaged 5-port switch from B&B electronics
- Mobile Mark 806-870/ 1850-1990 MHz unity gain surface-mount white antenna. Includes 15' RG58 and installed SMA (SubMiniature version A) connector
- VarTech Systems Model #: VT121WHB2-201-2-00-28-JB
- Combiner from doti-optics.com, contact person Monty Ma Gill, Displays & Optical Technologies, 110 Market Street, Georgetown, TX 78626, Phone: 512-246-6400, mmagill@doti-optics.com
- Delphi Automotive Radar: ESR
- Trimble SPS855 GNSS receiver with Zephyr Model 2 Rugged antenna
    - 91555-00 GNSS, Marine SPS855, No Radio - Kit, Including:
        - IS59827-72 Upgrade - Precise Rover, SPS985 / SPS855, Marine
        - IS51951-21 Option GLONASS (Globalnaya Navigazionnaya Sputnikovaya Sistema) SPSx5x / SPS985 Marine
        - IS59827-25 Heading & Moving Base, SPS985 / SPS855, Marine
        - 66241-00 Antenna - Zephyr Model 2 Rugged

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- 78235-00 Cable - Data/Power, 1.2 m
- 58957-15 Cable - GPS, 15 m, TNC/TNC Right Angle

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APPENDIX H:
GPS DAS DATA LOG EXAMPLE

putime,ip,pid,cellmodem_ip,cellmodem_rssi,correction_length,correction_state,correction_status,gps_status,heading,height,hud,hud_view,lanewarning[0],lanewarning[1],lanewarning_offset,latitude,loadavg_1,loadavg_15,loadavg_5,longitude,plow,position_quality,position_state,position_time,position_x,position_y,radar_state,radar_status,radar_temp,radar_tracking,uptime,vel_x,vel_y

1425324262.416781,"192.168.1.2",2079,"166.139.104.245",-75,311,True,4000,1003,1.207103,1849.489990,False,0,False,False,0.000000,0.686210,1.630000,0.280000,0.720000,-2.102032,True,3,True,69862.296875,2134727.321862,684350.928420,True,1,47,0x12,132.920000,-0.151277,-1.200238

1425324272.420233,"192.168.1.2",2079,"166.139.104.245",-75,311,True,4000,1003,1.169001,1850.557007,False,0,False,False,0.000000,0.686210,1.630000,0.280000,0.720000,-2.102032,True,3,True,69872.296875,2134726.919546,684351.128184,True,1,47,0x11,132.920000,-2.840687,1.274996

1425324282.423635,"192.168.1.2",2079,"166.139.104.245",-75,310,True,4000,1003,2.676145,1849.060059,False,0,False,False,0.000000,0.686210,1.630000,0.280000,0.720000,-2.102031,True,3,True,69882.296875,2134729.640279,684351.215917,True,1,47,0x13,132.920000,-1.597469,-3.046912

1425324292.426962,"192.168.1.2",2079,"166.139.104.245",-75,311,True,4000,1003,2.332921,1850.217041,False,0,False,False,0.000000,0.686210,1.630000,0.280000,0.720000,-2.102031,True,3,True,69892.296875,2134728.506816,684351.267283,True,1,47,0x14,132.920000,-0.007989,0.004859

1425324302.430328,"192.168.1.2",2079,"166.139.104.245",-75,311,True,4000,1003,0.478498,1852.593994,False,0,False,False,0.000000,0.686211,1.480000,0.340000,0.840000,-2.102032,True,3,True,69902.296875,2134725.328344,684352.324571,True,1,47,0x14,192.970000,-3.775119,-1.677613

1425324312.433734,"192.168.1.2",2079,"166.139.104.245",-75,310,True,4000,1003,1.164686,1851.230957,False,0,False,False,0.000000,0.686211,1.480000,0.340000,0.840000,-2.102032,True,3,True,69912.296875,2134726.014392,684351.658311,True,1,47,0x16,192.970000,0.070659,0.020275

1425324322.437057,"192.168.1.2",2079,"166.139.104.245",-75,311,True,4000,1003,-1.958947,1850.519043,False,0,False,False,0.000000,0.686211,1.480000,0.340000,0.840000,-2.102032,True,3,True,69922.398438,2134725.984768,684351.588019,True,1,47,0x17,192.970000,1.006441,-0.298944

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1425324332.441738,"192.168.1.2",2079,"166.139.104.245" ,-75,311,True,4000,1003,0.095305,1851.890015,False,0,False,False,0.000000,0.686211,1.480000,0.340000,0.840000,-2.102032,True,3,True,69932.398438,2134726.586403,684351.881045,True,1,47,0x17,192.970000,0.189749,-0.293186

1425324342.445073,"192.168.1.2",2079,"166.139.104.245" ,-75,310,True,4000,1003,-0.301003,1852.167969,False,0,False,False,0.000000,0.686211,1.480000,0.340000,0.840000,-2.102032,True,3,True,69942.398438,2134727.097091,684352.009553,True,1,47,0x16,192.970000,-0.004567,-0.052077

1425324352.449011,"192.168.1.2",2079,"166.139.104.245" ,-75,311,True,4000,1003,0.990820,1852.204956,False,0,False,False,0.000000,0.686211,1.480000,0.340000,0.840000,-2.102032,True,3,True,69952.398438,2134725.770306,684352.352933,True,1,47,0x17,192.970000,-0.097920,-0.064970

1425324362.453094,"192.168.1.2",2079,"166.139.104.245" ,-75,311,True,4000,1002,-1.822172,1853.067993,False,0,False,False,0.000000,0.686210,1.380000,0.410000,0.930000,-2.102032,True,2,True,69962.398438,2134727.628471,684350.374511,True,1,47,0x11,253.010000,0.589638,-0.017434

1425324372.457204,"192.168.1.2",2079,"166.139.104.245" ,-75,310,True,4000,1002,-0.325778,1863.394043,False,0,False,False,0.000000,0.686211,1.380000,0.410000,0.930000,-2.102031,True,2,True,69972.398438,2134732.493081,684354.502773,True,1,48,0x17,253.010000,-0.144898,1.989931

1425324382.461137,"192.168.1.2",2079,"166.139.104.245" ,-75,311,True,4000,1004,-1.513234,1860.093018,False,0,False,False,0.000000,0.686212,1.380000,0.410000,0.930000,-2.102027,True,4,True,69982.398438,2134752.371168,684359.661951,True,1,48,0x14,253.010000,2.560259,0.128598

1425324392.465249,"192.168.1.2",2079,"166.139.104.245" ,-75,311,True,4000,1004,-1.173309,1860.150024,False,0,False,False,0.000000,0.686213,1.380000,0.410000,0.930000,-2.102021,True,4,True,69992.398438,2134779.519834,684367.725731,True,1,48,0x14,253.010000,2.489652,1.024325

1425324402.469409,"192.168.1.2",2079,"166.139.104.245" ,-75,310,True,4000,1004,-1.514605,1860.222046,False,0,False,False,0.000000,0.686214,1.380000,0.410000,0.930000,-2.102015,True,4,True,70002.398438,2134808.082821,684371.899986,True,1,48,0xC,253.010000,2.629446,0.451422

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1425324412.473634,"192.168.1.2",2079,"166.139.104.245",-75,311,True,4000,1004,-1.165628,1860.269043,False,0,False,False,0.000000,0.686214,1.380000,0.410000,0.930000,-2.102013,True,4,True,70012.398438,2134817.749596,684374.679923,True,1,48,0xB,253.010000,-0.015770,-0.027474

1425324422.476934,"192.168.1.2",2079,"166.139.104.245",-75,311,True,4000,1004,-1.165628,1860.258057,False,0,False,False,0.000000,0.686214,1.050000,0.440000,0.940000,-2.102013,True,4,True,70022.398438,2134817.752191,684374.677802,True,1,48,0xC,313.040000,0.019336,-0.037787

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APPENDIX I:
DOCUMENTATION FOR DAS MAP INSTALLATION UPDATE

Provided by Bryan Newstrom, MTS Systems Corporation
July, 2015

This appendix documents the process for updating the DAS map. The map will need to be updated any time road geometry changes. This will typically be after road construction including lane modifications.

For any issues or questions, contact:

Bryan Newstrom
MTS Systems
Phone: 952-937-4686
Bryan.Newstrom@mts.com

Related Files

install_map.sh – shell script to build and install new database
lanewarnings.xml - data file used to create lane warning 3D scenery (red lines in HUD)
scene.xml - data file used to create 3D scenery for HUD
shapefiles/ - directory of existing shapefiles for map database (see below for brief descriptions)

Requirements

1. Laptop
    a. A ssh/scp (Secure Shell / Secure Copy) client and knowledge of how to use it
    b. The only way to copy files to DAS computer is to use a scp client[7]
    c. The only way to run commands on the DAS computer is to remotely login using an ssh client. Telnet will not work, and is not secure.
        i. For windows, PuTTY will work[8]
        ii. In Linux, use the standard ssh command
    d. Familiarity with running command-line programs
2. Ethernet cable
    a. Set laptop wired Ethernet to:
        i. IP address 192.168.1.100
        ii. Netmask 255.255.255.0
3. Access to a DAS computer
    a. The install process must be done on a DAS computer

[7] For Windows, a good client is WinSCP, http://winscp.net/eng/index.php while in Linux, you can use the built-in (already installed) scp command.
[8] http://www.chiark.greenend.org.uk/~sgtatham/putty/

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b. The programs used to process the shapefiles into a map database are only available on the DAS computers

DAS Computer Access

- IP address of DAS computer: 192.168.1.2
- Netmask of DAS computer: 255.255.255.0
- user: root
- password: xxxx

Steps for Uploading a New Map to the Blower Computer

1) Required files:
- donnerpass.zip - the new updated database files
- demo.sh - bash script to switch blower to demo mode
- SSH (Secure Shell) client program, or a Linux machine or Cygwin for Windows with SSH installed.

2) Critical information:
- computer IP (Internet Protocol) address: 192.168.1.2
- user: root
- password: xxxx
- all DAS software is installed in /ivlab

To update database:

1) Plug a laptop into network on blower
2) Copy new database to computer by typing following command in Putty window or Linux terminal:
    a. scp donnerpasss.zip root@192.168.1.2:/ivlab/databases
3) Login to computer typing following in Putty window or Linux terminal:
    a. ssh root@192.168.1.2
4) Move old database by typing the following in Putty window or Linux terminal:
    a. cd /ivlab/databases
    b. mv donnerpass donnerpass.org
5) Extract database using the unzip by typing in Putty window or Linux terminal:
    a. unzip donnerpass.zip
6) Reboot computer by typing "reboot" in the Putty window or Linux terminal:
    a. reboot

To run in demo mode

1) Copy demo.sh to computer
    a. scp demo.sh root@192.168.1.2:/ivlab/hud
2) Login to computer
    a. ssh root@192.168.1.2
3) Run script
    a. cd /ivlab/hud
    b. ./demo.sh

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or

c. bash ./demo.sh

4) Reboot to get back to normal

Contents of the "demo.sh" shell script

```
#! /bin/bash
sv stop heading
sv stop mbase
sv stop vs2gpsheading
export PATH=$PATH:/ivlab/bin
export LD_LIBRARY_PATH=$LD_LIBRARY_PATH:/ivlab/lib
export DB=`yacsget http://localhost/system /db`
export PROJ=`yacsget http://localhost/system /proj`
sim_gps_db -d $DB -p $PROJ -q -s -S1.0 &
vsgps $PROJ http://localhost/sensors &
```

List of files contained in donnerpass.zip:

- boundary.dbf
- boundary.prj
- boundary.qix
- boundary.shp
- boundary.shx
- crossovers.dbf
- crossovers.prj
- crossovers.qix
- crossovers.qpj
- crossovers.shp
- crossovers.shx
- drain_inlet_outline.dbf
- drain_inlet_outline.prj
- drain_inlet_outline.qix
- drain_inlet_outline.shp
- drain_inlet_outline.shx
- guardrails.dbf
- guardrails.prj
- guardrails.qix
- guardrails.qpj
- guardrails.shp
- guardrails.shx
- lane.dbf
- lane.prj
- lane.qix

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- `lane.shp`
- `lane.shx`
- `lanemarking.dbf`
- `lanemarking.prj`
- `lanemarking.qix`
- `lanemarking.qpj`
- `lanemarking.shp`
- `lanemarking.shx`
- `lanewarnings.osgb`
- `right_shoulder.dbf`
- `right_shoulder.prj`
- `right_shoulder.qix`
- `right_shoulder.qpj`
- `right_shoulder.shp`
- `right_shoulder.shx`
- `scene.osgb`

Installing a New Map Database

Use the shapefiles in the included shapefiles directory as a starting point. Add, remove, or edit data in these files. Respect file names and column attribute names and types. Any changes to the shapefile names or column attributes names or types will cause an error during install.

To install new map database

You will be running commands on the DAS computer as the root user.
Take care in what commands you run, since the root user can do anything!

1. Cross fingers…
2. Plug laptop computer Ethernet cable into network switch on vehicle
    a. The switch should be located close to the DAS computer
3. Start vehicle and turn on DAS
4. Copy files to DAS computer using scp client with credentials listed above
    a. Needed files:
        i. install_map.sh
        ii. lanewarnings.xml
        iii. scene.xml
        iv. shapefiles directory with updated shapefiles (directory must be named shapefiles)
    b. The easiest way would be to assemble all files in a directory then copy the directory to the DAS computer

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5. Login to DAS computer using ssh using credentials listed above
    a. cd to directory with files
    b. Run "./install_map.sh"
    c. If you get an error message like "bash: ./install_map.sh: Permission denied"
        i. Run "chmod +x install_map.sh", then try again
        ii. Or run "sh ./install_map.sh"

6. If successful, you should see output similar to:

```
creating directory to build new map ...
** success **
tiling and indexing new map ...
boundary
crossovers
drain_inlet_outline
entranceexits
guardrails
lanemarking
lane
right_shoulder
** success **
creating HUD 3D scenery new map ...
** success **
backing up old map ...
** success **
installing new map ...
** success **

** done **
new map installed to: /ivlab/databases/donnerpass
old map copied to: /root/installer/oldmap
to clean up run:
rm -r oldmap*
rm -r newmap
```

7. On error, the output will end with an error message
    a. Copy the error message for reference
8. Clean up
    a. Copy any wanted files back to the client computer
    b. Delete the directory with install process files
        i. The DAS computer has a 4 GB solid-state hard drive with plenty of extra space, so simply keeping the files should be OK.
9. Run "reboot"
    a. This will reboot the DAS computer. On startup, the new map database will be used.
10. Take the vehicle for a test drive in high-visibility conditions to verify new data using the HUD

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Additional Information

The files created for the new map will be installed to /ivlab/databases/donnerpass. This directory can be copied and saved and used to update the other DAS computers. Once you know the databases is good to go, just copy this directory to any of the other DAS computers that operate in the same geographic area. This way you can skip the above install process. Do not use this directory of shapefiles for the install process—i.e. don't install the already installed database.

Existing Shapefiles

Coordinate system:

NAD83 HARN California Zone 2
EPSG:2767

Units: meters

Shapefiles:

- boundary: used for RoadBoundary
- crossovers: LaneMarking for crossovers in median
- drain_inlet_outline: LaneMarking for drain inlet outlines
- entranceexits: LaneCenters for freeway entrances and exits
- guardrails: guardrail geometry
- lane: LaneCenters for traffic lanes
- lanemarking: all LaneMarking for traffic lanes and entrance/exit ramps
- right_shoulder: LaneMarking showing extent of right road shoulder

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