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DRAFT VERSION 1.0
FINAL REPORT
Evaluation Methods and Lessons Learned

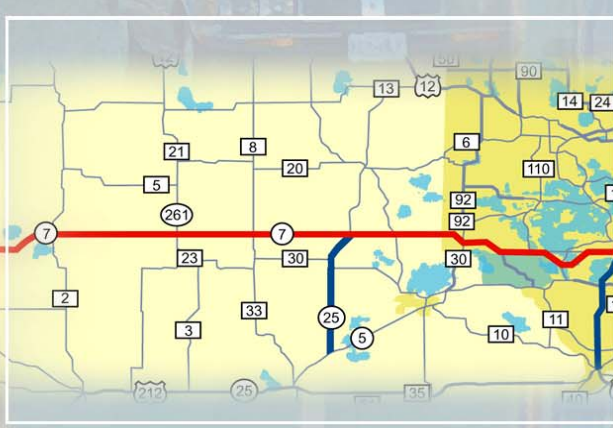
from the
Minnesota Department of Transportation
Intelligent Vehicle Initiative Field Operational Test

U.S. Department of Transportation
Federal Highway Administration

NHTSA
People Saving People

FMCSA
Federal Motor Carrier Safety Administration

September 26, 2003



Battelle
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Evaluation Methods and Lessons Learned from the Minnesota Department of Transportation Intelligent Vehicle Initiative Field Operational Test

for the

U.S. Department of Transportation
Washington D.C.

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by

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. . . Putting Technology To Work
505 King Avenue
Columbus, Ohio 43201

September 26, 2003

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EXECUTIVE SUMMARY

This report on the Evaluation Methods and Lessons Learned for the Mn/DOT Intelligent Vehicle Initiative (IVI) Field Operational Test (FOT) documents the goals and objectives, research approach, methods, and findings of a program to measure the feasibility and benefits of advanced safety systems for specialty vehicles. As part of the Intelligent Vehicle Initiative (IVI) sponsored by the U.S. Department of Transportation (USDOT), Mn/DOT tested technologies designed to provide operators of snowplows, ambulances, and police patrol cars a means to maintain desired lane position and avoid collisions with obstacles during periods of low visibility. This major project was a three-year effort to develop, test, and evaluate a lateral guidance and collision avoidance system to assist drivers under adverse weather conditions such as blowing snow, fog, and rain. USDOT selected Battelle to perform an independent evaluation of the technologies being tested. This operational test was intended to influence deployment decisions for public and private fleets by defining benefits and costs.

The FOT was conducted under Minnesota Guidestar, the state's program for Intelligent Transportation Systems research, testing, and deployment. The Mn/DOT Office of Advanced Transportation Systems (OATS) administered the program, which was conducted in partnership with the Federal Highway Administration, local government, private industry, and academia. The partnership consisted of the Minnesota Department of Transportation, the University of Minnesota, 3M, Altra Technologies, Hutchinson Health Care, McLeod County, and the Minnesota Department of Public Safety/State Patrol. Administrative and project management support were provided by URS/BRW.

The winter of 2001-2002 in the test area turned out to be uncharacteristically mild and relatively devoid of snow. During the period of the FOT, December 21, 2001 to March 31, 2002, there were only two snowfalls of significance. Furthermore, according to measurements made by the Mn/DOT FOT partnership, there was no occasion during the FOT in which the visibility was very low (defined as less than 100 meters) and there were only 15 minutes when visibility was in the 100 to 199 meter range. Thus, in the words of Mn/DOT project management: "At no time during the FOT were any of the specialty (vehicle) operators exposed for *sustained* periods to the kind of conditions for which the DAS (Driver Assistive System) was designed."

Evaluation Goals and Objectives

The primary goal of this IVI program was to determine the extent to which Intelligent Vehicle Safety Systems (IVSS) could help drivers drive more safely and, thus, reduce the number of specialty vehicle crashes, bodily injuries, and fatalities involving the subject vehicle population. Furthermore, the results of the FOTs were meant to be extended to estimate the safety benefits to society if all similar vehicles operating in the U.S. were to be equipped with the technology being tested.

In addition to estimating safety benefits, the evaluation meant to assess the benefits of IVSS in areas pertaining to the other national Intelligent Transportation System (ITS) goal areas of public mobility, efficiency and productivity, and environmental quality. Other goals included evaluating driver acceptance, stress, and workload; system performance; commercialization factors such as market acceptance, product maturity, and manufacturability; and institutional and legal issues affecting deployment.

The evaluation plan was organized around these broad IVI goal areas, within which research objectives were established. The evaluation partners through a workshop defined the overall goal areas and their relative priorities in December 1999. Each research objective had one or more testable hypotheses, which may be proved or disproved using data on specifically designed measures (variables or parameters).

IVSS Technology Tested

The Minnesota DOT tested technologies designed to provide operators of snowplows, ambulances, and patrol cars drivers a means to maintain desired lane position and avoid collisions with obstacles during periods of low visibility. Key among these technologies were a magnetic lane awareness system, vehicle guidance and driver interface, and collision warning systems with visual warnings and "virtual rumble strip" feedback from vibrating seat and auditory warnings.

Anticipated Outcome

The independent evaluation of the Mn/DOT IVI FOT was meant to provide the USDOT, other government agencies, specialty vehicle manufacturers, equipment and technology developers, DOTs, public safety officials, and others in the transportation field with valuable information on the advantages and risks of deploying IVSS in the field. The evaluation was intended to result in

- Information on actual costs incurred in deploying, operating, and maintaining IVSS,
- First-hand reactions to the IVSS from drivers, fleet operators, and support personnel,
- Data on system performance on the road, and
- Analysis that puts the FOT results in the context of existing knowledge on transportation safety.

Data Sources

Data for the evaluation were of five types:

- **Historical and FOT Crash/Incident Data.** Databases on snowplow, ambulance, and patrol car crashes and relevant incidents in adverse weather were used to identify relevant crash types and pre-crash scenarios and establish the crash incidence and distribution "without" the IVSS.

- **Onboard Driving Data.** Onboard data acquisition systems were intended to provide considerable information on the operation of the specialty vehicles with and without the IVSS driver interface activated. The data were meant to be used to determine how often and under what circumstances possible pre-crash conflicts occurred and to support statistical models to estimate crash probabilities. Limited driving data were collected on the IVSS-equipped vehicles during the FOT.

- **Surveys and Interviews.** Opinions were sought from personnel in the FOT (including drivers, mechanics, and dispatchers). These opinions were used to gauge the level of user acceptance.

- **Vehicle Operations Records.** The operator's maintenance and operation records that were relevant to the FOT were examined to help evaluate system reliability and performance and were meant to estimate the costs or savings associated with the IVSS.

- **Special Tests and Supplemental Data.** All data originating outside the FOT itself. The most significant of the special tests were simulator tests performed at the University of Minnesota's Intelligent Vehicles Laboratory and the Beta tests performed in advance of the formal FOT. Data were also desired from representatives whose thoughts were especially important for identifying institutional and legal issues as well as projecting the possible market penetration of the systems.

Analysis Methods

The results from the various data sources were meant to be combined into comprehensive analyses. These analyses were meant to cover broad goal areas such as: safety, mobility, productivity, efficiency, environmental benefits, human factors, system performance and functionality, product maturity for deployment, and institutional and legal issues that may affect deployment.

Statistical comparisons of driving data with and without the IVSS were intended, and those results were meant to be applied to historical database information to estimate the safety benefits of the IVSS. The safety benefits estimation was key to many of the outcomes of the evaluation, in that the numbers of crashes avoided and the severity of those crashes were meant to become factors in calculating benefits to society and other effects of the IVSS. Mobility benefits to the general public, for example, would be based on the numbers of crashes avoided, and the value of the benefit would be determined by a review of the literature.

Productivity, efficiency, and environmental effects were meant to be measured using literature values, supplemented with cost and performance data from the FOT participants. A formal benefit – cost analysis (BCA) was intended, to compare the net total benefits to society with the net total cost for deploying the IVSS, over the expected life of the systems. Human factors, such as usability, driver perceptions of workload and stress, effects on driver risk and vigilance, and driver perceptions of product quality and maturity, were evaluated.

Data were drawn from the on-board vehicle data acquisition system (vehDAQ), weather information, dispatch log, and other sources of supplemental data. Data structures and storage systems were put in place, and the bulk of the data management activity for the evaluation involved the University of Minnesota. The Battelle and University of Minnesota work was coordinated to avoid duplication in the areas of data analysis and human factors and provide for more depth in the evaluation.

Schedule

The Mn/DOT FOT began on October 1, 2001. Data collection was begun on December 21, 2001 and continued until March 31, 2002.

Weather Effects on FOT Results

As stated earlier, the winter of 2001-2002 in the test area turned out to be uncharacteristically mild and relatively devoid of snow. Both the operators of the FOT and the independent evaluator were hoping that the test area would experience at least a typical level of adverse weather conditions during that winter season, in order to have plentiful data to analyze. But the winter weather during the FOT did not supply the desired conditions for the needs of the test. The lack of low-visibility conditions in particular affected not only the goals and objectives of the evaluation but those of the FOT as well. The relative scarcity of snowfalls greatly reduced the expected volume of data collected during the FOT and, consequently, the results experienced as a result of implementing the IVSS technologies.

As a result, FHWA determined that Battelle's evaluation efforts should focus on two activities: (1) documenting the evaluation methods and lessons learned, and (2) performing an assessment of the drivers' acceptance of IVSS. This report presents findings related to the first goal. Findings will be given where sufficient data existed to draw conclusions, but since data in many areas were insufficient, the approach that would have been taken had there been sufficient data is presented. The separate *Mn/DOT Driver Acceptance: IVI FOT Evaluation Report*, Battelle, 2003 addresses the second goal.

ACKNOWLEDGEMENTS

Battelle would like to thank the Mn/DOT Partners for their cooperation with our independent evaluation of this Intelligent Vehicle Initiative Field Operational Test. In particular we would like to recognize the personnel of the Minnesota Department of Transportation, Office of Advanced Transportation Systems (OATS); the Mn/DOT Metro District Eden Prairie and Shakopee garages; the combined Mn/DOT District 8/McLeod County garage at the Hutchinson Area Transportation Systems (HATS); the Minnesota State Patrol; the Hutchinson Health Care organization; the University of Minnesota Human Factors Research Laboratory, Intelligent Vehicle Laboratory, and ITS Institute; and the URS/BRW Minneapolis office. Personnel from each of these organizations freely provided their time and assistance in support of our evaluation, which Battelle sincerely appreciates.

ABBREVIATIONS

ATA	American Trucking Association
AUI	Auditory user's interface
BCA	Benefit-cost analysis
BCR	Benefit-cost ratio
BOA	Basic order agreement
B&W	Black & white
CC	Configuration control
CCD	Charge coupled device
COTR	Contracting officer's technical agent
CPU	Central processing unit
CWS	Collision warning system
DAS	Driver assistive system
DGPS	Differential global positioning system
DIMM	Dual In-line memory module
DSQ	Driver driving style questionnaire
DVC	Digital videocassette
DVD	Digital video data
FOT	Field operational test(s)
FTP	File transfer protocol
GES	General Estimates System
GIS	Geographic information systems
GPS	Global positioning system
GUI	Graphical user's interface
HUD	Heads-up display
HUI	Haptic user's interface
IMU	Inertial measurement unit
IPAS	ITS Program Assessment Support
ITS	Intelligent Transportation Systems
IVI	Intelligent Vehicle Initiative
IVSS	Intelligent Vehicle Safety System(s)
JPEG	Joint Photographic Experts Group (graphic standard)
LED	Light-emitting diode
MCMIS	Motor Carrier Management Information System
MLD	Mirror-mounted LED display
MPEG	Motion Picture Experts Group (graphic standard)
MVR	Meteorological Visual Range
NASS	National Automotive Sampling System
NHTSA	National Highway Traffic Safety Administration
ODBC	Open database connectivity
O&M	Operating and maintenance
OATS	(Mn/DOT) Office of Advanced Transportation Systems
PAR	Police accident report
PCI	Peripheral component interconnect
RAM	Random access memory

RF	Radio frequency
R/WIS	Road/weather information system
SAS	Statistical Analysis System®
SQL	Structured query language
SCSI	Small computer sensor interface
SVRD	Single vehicle roadway departure
SWAT	Subjective workload assessment technique
TH	Trunk highway
TIFA	Trucks involved in fatal accidents
TIS	Traveler Information System
TRS	Technical system requirements
USDOT	United States Department of Transportation
vehDAQ	Vehicle Data Acquisition System
WBS	Work breakdown structure

1.0 INTRODUCTION

The United States Department of Transportation (USDOT) established an Intelligent Vehicle Initiative (IVI) as a major component of the Intelligent Transportation System (ITS) program. The intent of the IVI is to improve the safety and efficiency of motor vehicle operations significantly by reducing the probability of motor vehicle crashes. These safety improvements could also show secondary benefits such as increased transportation mobility, productivity, or other operational improvements.

In 1999, USDOT entered into cooperative agreements with four partnerships to conduct Generation 0 Field Operational Tests (FOTs) of advanced intelligent vehicle safety systems (IVSS). These systems are expected to begin production preparations before the end of fiscal year 2003. Although the scope of the IVI Generation 0 FOT program included light passenger vehicles and transit vehicles, USDOT selected one FOT involving specialty vehicles and three FOTs involving commercial trucks:

- Minnesota DOT tested technologies designed to provide operators of snowplows, ambulances, and patrol cars drivers a means to maintain desired lane position and avoid collisions with obstacles during periods of low visibility. Key among these technologies was vision enhancement, lateral guidance, and collision warning systems.

- Volvo Trucks North America, Inc., in partnership with U.S. Xpress, tested a forward collision warning system, a blind spot warning system (not under evaluation), an adaptive cruise control, and an advanced electronic braking system for commercial vehicles

- Mack Trucks, Inc., in partnership with McKenzie Tank Lines, will test a trucker safety advisory system and a lane departure warning system for commercial vehicles

- Freightliner Corporation, in partnership with Praxair, tested a roll stability advisor and a roll stability control to assist commercial vehicle drivers in avoiding rollover crashes.

Each team proposed a separate operational test to demonstrate and evaluate advanced technologies. As part of this effort, the USDOT selected a Battelle-led team to work with each partner to perform an independent evaluation of the technologies being tested. In each case, the primary evaluation goal of the FOT was to determine the potential safety benefits of IVSS. Specifically, how many crashes, injuries, and fatalities could be avoided if all such vehicles were equipped with these technologies? It was also important to understand how these technologies affected driver performance. For example, did drivers drive more safely? And, how did these technologies affect driver stress level and workload? The secondary goals of these evaluations included the estimation of other benefits (mobility, efficiency, productivity, and environmental quality), evaluation of system performance, and assessments of other factors that affect development and deployment of these technologies. These factors included user acceptance, product maturity, manufacturability, and institutional and legal issues.

Mn/DOT deployed IVSS technologies designed to provide vision enhancement, lateral guidance, and collision warnings. The IVSS being tested in the Mn/DOT FOT were designed for use in snow accompanied by low visibility conditions. Thus, such conditions were necessary to achieve the goals and objectives of the Mn/DOT FOT as well as its independent evaluation by Battelle. However, the winter of 2001-2002 in the test area turned out to be uncharacteristically mild and relatively devoid of snow. During the period of the FOT, December 21, 2001 to March 31, 2002, there were only two snowfalls of significance. Furthermore, according to measurements made by the Mn/DOT FOT partnership, there was no occasion during the FOT in which the visibility was very low (defined as less than 100 meters) and there were only 15 minutes when visibility was in the 100 to 199 meter range.

Thus, in the words of Mn/DOT project management: “At no time during the FOT were any of the specialty (vehicle) operators exposed for *sustained* periods to the kind of conditions for which the DAS (Driver Assistive System) was designed.” As a result, FHWA determined that Battelle’s efforts should focus on two activities: (1) documenting the evaluation methods and lessons learned, and (2) performing an assessment of the drivers’ acceptance of IVSS. This report presents findings related to the first goal. The separate *Mn/DOT Driver Acceptance: IVI FOT Evaluation Report*, Battelle, 2003 addresses the second goal.

1.1 The Mn/DOT IVI Field Operational Test

The Mn/DOT IVI FOT was conducted by a partnership including state and local government, industry, and the University of Minnesota. Table 1-1 lists the partnership organizations and their roles. URS/BRW provided administrative and program management support to Mn/DOT on the project.

Table 1-1. Roles of the Mn/DOT FOT Partners

ORGANIZATION	ROLE
Mn/DOT Office of Advanced Transportation Systems (OATS)	Overall project manager as caretaker of Minnesota Guidestar Program. Facilitated contracts preparation and approval.
University of Minnesota (Intelligent Vehicle Laboratory, Human Factors Research Laboratory, and the Department of Applied Economics)	Technical lead & system integrator. Human factors support & evaluation. Benefit-cost analysis.
Mn/DOT – District 8	Provided 2 snowplows with operators. Resident district for magnetic tape installation. Provided office space in Hutchinson Area Transportation Systems (HATS) building.
Mn/DOT – Metro Division	Provided 1 snowplow with operators.
Minnesota State Patrol	Provided 1 state patrol car with operator.
McLeod County	Provided 1 snowplow with operators.
Hutchinson Health Care	Provided 1 ambulance with operators.
3M Corporation’s ITS Project Office	Provided magnetic lateral guidance tape and sensor technologies.
Altra Technologies, Inc. (ATI)	Provided side-looking radar system.

The Mn/DOT IVI effort was focused on improving mobility and reducing the number and severity of specialty vehicle (especially snowplow) crashes with other vehicles and roadside equipment such as guardrails and traffic control devices. Such crashes sometimes occur under low-visibility conditions caused by fog, rain, blinding snow, and darkness. Specific goals of the FOT included:

- Reducing the number and severity of specialty vehicle collisions as well as rear-end collisions involving the public's vehicles hitting the backs of snowplows,
- Improving the productivity and efficiency of snowplow and emergency vehicle operations, and
- Successfully integrating systems and technologies tested in earlier Mn/DOT projects.

Overall, the Mn/DOT FOT proposed to build upon and to extend several ITS technologies investigated in past and ongoing efforts in the state of Minnesota. The purpose of the FOT was to establish safety benefits. The IVSS were focused on providing specialty vehicle drivers with assistance during low-visibility conditions. In the FOT there were four snowplows, one state highway patrol automobile, and one ambulance equipped with the technologies, as well as an infrastructure to support them. A number of distinct yet related systems were integrated into the IVSS using on-board processing. These included:

- **Magnetic Roadway Tape, Magnetic Lateral Guidance, DGPS, GIS Mapping**
    - these technologies were provided in order to improve vehicle guidance performance, improve lane-keeping abilities, and reduce crashes with infrastructure

- **Forward- and side-looking radars and associated collision warnings**
    - these technologies were provided in order to help avoid collisions

- **Heads-up display (HUD), auditory warnings, haptic feedback**
    - the HUD presented drivers with lane-keeping markers and iconic representations of objects in the roadway that were threats
    - the visual, auditory and haptic (seat vibration) systems provided drivers/operators with lane departure and collision avoidance warnings

- **On-board vehicle Data Acquisition System (vehDAQ)**
    - this data acquisition system received output from various subsystems as well as driver performance data and stored the data for subsequent analysis.

The FOT was conducted from December 22, 2001 to March 31, 2002. During the FOT, the test vehicles operated on their usual state and county highway routes. The primary test road for the FOT was a 45-mile section of Minnesota Trunk Highway 7 (TH-7) that runs east-west between the I-494 beltway in Minnetonka (a community on the western side of Minneapolis) and the City of Hutchinson. There was also a 4-mile section of McLeod County Road 7 extending northeast from Hutchinson that was included in the FOT.

1.2 Organization of This Document

This report is divided into seven sections. Section 2 describes the IVI systems that were tested, the research plan and experimental design originally intended to evaluate these systems, and the operational characteristics that affected the evaluation. Section 3 contains a comprehensive discussion of the original evaluation goals and objectives and discusses the FHWA's redirection as a result of the mild winter weather conditions experienced. Section 4 is an overview of the evaluation approach. Section 5 describes all the data that were collected. Section 6 describes the analysis methods used and the results of those analyses. Section 7 summarizes our recommendations for future FOTs.

2.0 DESCRIPTION OF THE IVSS AND THE FOT

The IVSS technology deployed in the Mn/DOT IVI Field Operational Test was designed to provide a driver the means to maintain desired lane position and avoid collisions with obstacles during periods of low visibility. This program was motivated by the fact that specialty vehicles often must operate under inclement weather conditions. Typically associated with these inclement weather conditions are low-visibility situations. The IVSS' driver assistive system (DAS) improved safety for the specialty vehicle operator by providing the necessary cues for lane keeping and collision avoidance normally unavailable during poor-visibility conditions. The DAS, placed in public safety vehicles, also was meant to improve safety conditions for the general public by facilitating all-weather emergency services, and in the case of snowplows, opening roads and keeping them passable in heavy weather for other emergency vehicles and the general motoring public.

The primary focus of the project was snowplows; however, an ambulance and police vehicle were also included. The Mn/DOT FOT project implemented, operated, and evaluated all necessary infrastructure, in-vehicle sensing technology, in-vehicle processing including algorithms, and driver-vehicle interfaces. The FOT partners expected to test these systems on state and county highways using vehicles under low-visibility conditions such as blowing snow. The system was also intended to help drivers when visibility may be good but lane markings are obscured. The results of the Mn/DOT FOT were originally meant to provide the Federal Highway Administration and the independent evaluator with data, and to inform decision makers and the general public of the potential for these systems to improve the safety and productivity of the transportation system.

Section 2.1 describes the technology that was tested. Section 2.2 presents the research plan that was followed, including information on the FOT design, drivers and vehicles, routes, and scheduling system. Section 2.3 identifies operational characteristics that affected the evaluation of the FOT.

2.1 Description of the IVI Technologies

The Mn/DOT IVI FOT was part of a national demonstration program looking at new Intelligent Vehicle Safety System (IVSS) technology in three types of specialty vehicles. The FOT involved:

- Four snowplows (three from Minnesota DOT districts and one from McLeod County),
- One Minnesota State Patrol car, and
- One ambulance (belonging to Hutchinson Health Care).

The technology featured a Driver Assist System (DAS) designed to help drivers "see" the roadway ahead when visibility is very poor, by helping maintain desired lane position and avoid collisions with obstacles. In snowplows, the IVSS technologies were intended to open roads faster and keep them passable in adverse weather. In the state patrol car and ambulance, the technologies were intended to help improve all-weather emergency services. Both were meant to improve safety conditions for the general public. All of the six test vehicles had in-vehicle equipment installed that included sensing technology, processing capability, and driver-vehicle interfaces.

2.1.1 Technology Overview

The technologies that the Mn/DOT partnership deployed and tested include:

- Magnetic roadway tape/magnetic lateral positioning system,
- Differential global positioning system (DGPS),
- Geographic information system (GIS) mapping,
- Forward- and side-looking radar,
- On-board Vehicle Data Acquisition System (vehDAQ), and
- Driver Assistive System (DAS), including:
  - Heads-up display (HUD),
  - Collision warning (visual, auditory and haptic warnings), and
  - Forward and side collision warning systems.

A Rear-looking Radar and its associated External Light Warning System, both of which had been originally planned for the snowplows only, were ultimately not included in the IVSS. Also, the MVRI visibility index described in the MnDOT Design Document was not implemented.

Vehicle positioning, collision avoidance, and the driver interface made up the primary components of the DAS. Vehicle positioning was accomplished through a combination of a Differential Global Positioning System (DGPS) with geospatial database system and a roadway magnetic tape/magnetic sensor-based system. The magnetic tape was installed along 2 segments for a total of 12 roadway miles, which was approximately one-fourth of the total test road length. Collision warning and avoidance were accomplished with radar sensors and signal processing techniques that took advantage of information returned by the vehicle positioning system. The driver interface system provided information to the driver and employed visual, haptic, and auditory interfaces to provide an optimal information path to the driver. The system worked as follows:

DGPS and the magnetic tape system provided information regarding the position of the vehicle. The DGPS provided global positioning information, and the magnetic tape system provided local positioning information in the form of lateral displacement of the vehicle from the lane's center (calculated from the offset of the magnetic sensor from the magnetic tape). An Inertial Measurement Unit (IMU) provided direction and speed information to the vehDAQ as well as vehicle orientation data (i.e., vehicle yaw, roll, and pitch rates, lateral, longitudinal, and vertical acceleration). Given vehicle position and orientation, the geospatial database was queried to determine the presence and location of all relevant items in the local landscape.

Simultaneously, the vehicle's forward-, side-, and (on the snowplows) rear-looking radar scanned the environment around the vehicle to detect the presence and location of obstacles. The range of the radar was 350 feet, and it detected both moving and stationary objects in the lane ahead, in adjacent lanes, in the entrance of intersecting roads, and on the hard shoulder within the sweep of the radar beam. The radar processor accepted the raw sensor data and compared them to the results of the geo-spatial database query. The radar processor then distinguished between radar returns that were a threat to a driver and radar returns that were associated with fixed elements of the infrastructure. When the driver was thus warned of the presence of potential obstacles, he or she could either stop or slow down and navigate around the vehicle ahead, as necessary.

2.1.2 Differential Global Positioning System (DGPS)

The DGPS infrastructure consisted of three DGPS correction broadcast stations at Silver Lake, Mayer, and Chanhassen, and high-accuracy geospatial databases. The correction stations consisted of towers, radio electronics, GPS antennae, and receivers. The DGPS correction signals provided the means with which to obtain high-accuracy vehicle position solutions in real time to enable vehicle lateral and longitudinal navigation and guidance capabilities. The high-accuracy digital geospatial database provided the roadway references used to maintain desired lane position.

Geospatial Database

The high-accuracy geospatial database provided the roadway references used to maintain desired lane position and also provided a means to filter from the vehicle operator, unwanted radar returns from stationary elements in the geospatial landscape. Although the digital geospatial database was carried on the vehicle and stored in computer memory, it was considered to be part of the DGPS system infrastructure in that it described the presence, location, and physical attributes of relevant elements of the road infrastructure.

Vehicle Design

The vehicle system can be viewed as the integration of four specific subsystems: the guidance system, the collision avoidance system, the computational system, and the driver interface system (also known as the human – machine interface). The guidance system consisted of three subsystems: the global positioning subsystem, the inertial measurement subsystem, and the guidance processor. The global positioning subsystem was used as the primary positioning sensor. The GPS subsystem consisted of a GPS receiver and antenna, an RF modem used to receive corrections from a base station, and an interface to a data acquisition or control computer.

GPS Interaction between Vehicle and Base Station

As soon as the DAS was turned on, the vehicle control computer requested a GPS correction from the nearest GPS tower. This request was broadcast from the vehicle to the tower. When the tower control computer detected the request, the tower began to broadcast its correction in the specified time slot. Once the tower broadcast its correction, the correction was received by the RF modem and passed to the vehicle control computer. The vehicle control computer used the on-board geospatial database to determine which GPS base station was closest to the vehicle.

System Response to Loss of GPS

In operation, with the loss of GPS, the vehicle's Inertial Measurement Unit (IMU) alone was designed to be used to provide sufficiently accurate lateral and longitudinal global information to operate the driver assistive system in its intended state for a period of a few seconds, giving longitudinal/preview information as well as lateral information. After this time, if no magnetic tape was available, the driver interface would inform the driver that assistance was no longer possible, and the system would revert to "stand by" until GPS lock was reacquired. If the magnetic reference system was available, the position processor was designed to provide sufficiently accurate information for approximately one additional minute to operate the driver assistive system in its intended state.

Once global position estimates were no longer sufficiently accurate and the magnetic reference was still available, the driver assistive system then supplied only lateral information to the driver via the normal channels (visual, haptic, and audible warning feedback). If GPS lock was reacquired, the system returned to its normal mode; if the vehicle operated beyond where the tape is located, the driver was informed and the driver assistive system reverted to "stand by" until either GPS returned or the vehicle was driven again over the tape, at which time the appropriate interface would have been provided.

2.1.3 Magnetic Lateral Guidance System

If GPS lock was lost while a vehicle was on a test corridor section where the magnetic tape was installed, magnetic lateral guidance was available as a backup lane-keeping system. It provided information indicating where the driver was on the road – laterally – by means of a moving "carrot" on a scale superimposed on the HUD. The vehicle's magnetic sensor(s) (two on each snowplow, one each on the ambulance and state patrol car) detected the distance from the sensor to the tape and a processor converted that into the carrot indicator that told the driver how far he or she was from the edge or center of the road. Magnetic lateral guidance did not give distance, however, so there were no virtual lane markings overlaying the road into the distance as there was with DGPS. For that reason, it is likely that operators using magnetic lateral guidance will drive more slowly than with DGPS-assisted guidance.

2.1.4 Driver Assistive System (DAS)

The DAS can be described as an integration of subsystems. The DAS integrated DGPS and magnetic tape-based vehicle positioning, digital geo-spatial databases, radar, computer processors, and the Head-Up Display that provided to the driver a virtual representation of the view out the windshield. This virtual view was most useful when the normal view out the windshield was diminished by blowing or drifting snow, rain, fog, or even darkness. The system displayed lane boundaries including turn lanes, and it displayed icons representing guardrails, jersey walls, and mailboxes so that the driver had the proper perspective. The system also displayed symbols for obstacles detected by radar such as stalled or slower-moving vehicles that presented a collision hazard.

The intent of the DAS was to improve safety. Vehicle positioning, collision warning, and the driver interface constituted the primary functional components of the DAS. Vehicle positioning was accomplished through a combination of a Differential Global Positioning System (DGPS) with geospatial database system and a roadway magnetic tape/magnetic sensor-based system. Forward collision warning was accomplished through radar sensors and signal processing techniques that took advantage of information returned by the vehicle positioning system. Side collision warning was accomplished through side-mounted presence detectors. The driver interface system provided information to the driver and employed graphical, haptic, and auditory interfaces to provide information to the driver.

The system worked as follows:

DGPS and the magnetic tape system provided information regarding the position of the vehicle. The DGPS provided global positioning information, and the magnetic tape system provided local positioning information in the form of lateral displacement of the vehicle from the lane's center (calculated from the offset of the magnetic sensor from the magnetic tape). An Inertial Measurement Unit (IMU) provided direction and speed information to the vehDAQ as well as vehicle orientation data (i.e., vehicle yaw, roll, and pitch rates, lateral, longitudinal, and vertical acceleration). Given vehicle position and orientation, the geospatial database was queried to determine the presence and location of all relevant items in the local landscape.

Simultaneously, the vehicle's forward- and side-looking radar scanned the environment around the vehicle to detect the presence and location of obstacles. The range of the forward-looking radar was 350 feet, and it detected both moving and stationary objects in the lane ahead, in adjacent lanes, in the entrance of intersecting roads, and on the hard shoulder within the sweep of the radar beam. The radar processor accepted raw forward-looking sensor data and compared them to the results of the geo-spatial database query. Detections that corresponded to vehicles in the opposing lanes of traffic were screened out during the processing of the forward-looking radar's data. The radar processor then distinguished between radar returns that were a threat to the driver and radar returns that were associated with fixed elements of the infrastructure. When the driver was thus warned of the presence of potential obstacles, he or she could either stop or slow down and navigate around the vehicle ahead, as necessary. The side-looking radar alerted a driver who had signaled a turn that a vehicle was on the side of the turn and represented a collision hazard.

DAS Interface

The DAS Interface provided the specialty vehicle operator with the following:

(1) Lane markings for lateral and longitudinal guidance,
(2) Lane departure warnings for lateral guidance,
(3) The presence and location of objects which could cause a collision, and
(4) Collision avoidance warnings.

Lane position and collision avoidance information were provided on the Head-Up Display, vibration in the driver's seat, and sound from speakers in the vehicle. The lane markings and lane departure warnings were derived from inputs provided by the DGPS and the geospatial database. The collision avoidance warnings were provided by a forward-looking radar system that detected and located obstacles ahead of the specialty vehicle. When the DAS was deployed, the operators were able to use this information to combat the effects of poor visibility if they were confronted by blowing or drifting snow, whiteout conditions, or fog, night, etc. The operators were able to use the lane markings and lane departure warnings to stay in their lane and the information about the presence and location of potential obstacles to avoid collisions.

The positional and collision avoidance information was presented via the DAS Interface. This interface consists of three displays:

(1) Head-Up Display (HUD). Visual information was provided via the HUD, which was a Graphical User Interface (GUI) that consisted of a combiner (a screen mounted between the driver and the windshield, and a projector positioned just to the right of the operator.

(2) Auditory User Interface. Auditory information was provided via two speakers mounted in the vehicle's cab. The objective of the audible interface was to provide to the driver a left or right *directional* cue or warning. To ensure that the cue is directional, the stereo speakers were mounted in the left and right driver's doors. When a lane departure left warning was required, only the left channel was activated, and *vice versa*. The sound more or less duplicated that of a vehicle driving over a rumble strip.

(3) Active Seat (Haptic User Interface). Vibrators installed in the left and right sides of the snowplow driver's seat bottom provided directional haptic information. The Haptic User Interface provided vibrational cues to the driver through the seat cushions. The vehicle seat was modified so that motors were embedded in the seat cushion; two motors were placed on the left and right sides in the bottom support. When a lane departure right warning was required, only the right side would vibrate.

Head-Up Display (HUD)

The HUD consisted of three components; the combiner and projector (and their associated mounting hardware) and the computer software that drove the images provided by the projector. The HUD provided continuous positional information by showing the edge- and centerline markings of the road ahead of the operator. When viewed by the operator, the edge- and centerlines of the image on the combiner overlaid the actual edge- line and centerline on the road ahead, so that in conditions of very poor visibility, the driver was able to drive by using the projected edge- and centerline markings instead of the actual lane markings.

The system worked as follows. The driver, during low-visibility conditions, folded the combiner down to its operational position that was approximately 18 inches in front of the driver's face. The driver then turned on the projector, which was located adjacent to the driver's right ear. The projector then provided the images that were used by the driver to guide the vehicle during low visibility conditions. The driver viewed the road ahead through the combiner, and also saw reflections of the projector in the combiner. Figure 2-1 shows a HUD image captured during daylight.

Figure 2-1. Head Up Display Image Captured at 30 MPH

Lane Markings

The HUD provided continuous positional information by showing the edge- and centerline markings of the road ahead of the operator. When viewed by the operator, the edgelines and centerlines of the image on the combiner overlaid the actual edgelines and centerline on the road ahead. That way, while in conditions of very poor visibility, the driver was able to drive by using the projected edgeline and centerline markings instead of the actual lane markings.

There are several types of environmental conditions in which this technology could help the driver by displaying lane markings. The most obvious was blowing snow or a snow cloud. Others included fog or heavy rain, which can occur outside of winter. There was also the condition in which visibility itself was not necessarily poor but snow covered the lane markings, perhaps because snowfall was not yet heavy enough to warrant plowing.

Lane Departure Warnings

Lane departure warnings were given to the operator as soon as one of the wheels of the operator's vehicle crossed a limit set by a driver[1]. These warnings were presented via (1) the HUD through roadway border color changes, (2) an auditory display, and (3) the active seat. The lane marker on the HUD changed color from white to red. The HUD changed color on the left side of the lane marker if the vehicle drifted out of the lane to the left, and it changed color on the right side if the vehicle drifted out of the lane to the right.

Simultaneously, a continuous rumbling sound was presented. The sound came from the left speaker if the vehicle was drifting out of the lane to the left, and from the right speaker for lane departure to the right. A continuous vibration was felt under the driver's thigh – along the left thigh if the vehicle was drifting out of the lane to the left, and vice-versa for the right. All three warnings were presented simultaneously if the vehicle started to leave the lane (assuming the combiner was folded down to give the visible warning and the volume was on for the audible warning). If the turn signal was switched on, the lane departure warning was deactivated.

System Indicators

There were 3 bars in the upper left-hand corner of the HUD. The longer uppermost bar gave DGPS status. The two shorter bars gave map and radar status. If any of these bars changed from a flashing green color, it indicated that a system problem was being experienced. If the whole screen went red, the driver needed to bring the vehicle to a safe stop then fold the HUD up to its storage position, continuing to drive with due caution if appropriate.

One exception to this rule was that if the vehicle had a DGPS failure while on the road sections that have magnetic tape, the driver would have been able to continue (though driving more slowly) because he or she would have had the indicator of distance between center of vehicle and center of lane. A flashing yellow DGPS bar meant DGPS accuracy was being reduced to between 8 to 20 inches, in which case the driver should have reduced speed and been prepared for a more severe failure. A flashing yellow bar may turn into a red screen or could go back to flashing green.

In normal operation, all three bars (DGPS, map, and radar status) flashed green, meaning that all aspects of the system were functioning properly. (If they were still green but not flashing, they were frozen and the driver should have reacted the same as if the screen was red). Also when the system was functioning properly, the driver got continuous lane position information on the HUD. If the vehicle started to drift out of the lane, a warning was provided via HUD, speakers, and active seat (unless the turn signal was on). If the vehicle was in danger of colliding with another object, the driver received a visual color-change warning from the HUD so that he or she could take appropriate action. If the driver assistive system was on but the HUD combiner was folded up, the driver would still get audible and haptic warnings for lane departure as well as side collision warning lights. However, folding the HUD combiner up removed the only means of displaying the forward collision warning symbology.

[1] For snowplow operations, operators typically plowed a few feet out of lane to ensure complete snow removal. In these situations, the operator preferred to choose his or her "out of lane" limits.

2.1.5 Radar-based Collision Warning/Sensing System

There are three subsystems that comprised the collision warning/sensor system: the forward-looking sensor subsystem, the side-looking sensor subsystem, and the rear-looking sensor subsystem. All 6 specialty vehicles were equipped with the forward- and side-looking systems.

Forward-looking Sensor System

The Eaton-Vorad EVT-300 radar provided not only range and range rate information, but also provided azimuth angle information to multiple targets. The geospatial database allowed the process to distinguish between fixed geospatial objects and, for instance, a stalled vehicle on the shoulder near a sign. Given the angular resolution of the radar sensor, the radar processor used the geospatial database to identify the sign as an item of "roadside furniture," and the stalled vehicle as a legitimate target. Therefore, the driver was warned that the stalled vehicle was there and poses a threat, but was not warned about the sign because it did not pose a threat.

Forward Collision Avoidance

The specialty vehicle operator was particularly concerned with vehicles ahead that are stationary or traveling more slowly. Warning the operator of the presence of such potential obstacles allowed him or her to take appropriate action, such as slowing down and/or navigating around the vehicle ahead. The forward-looking radar detected and located objects that potentially could become obstacles. This includes moving and stationary objects that were in the lane ahead, in adjacent lanes, in the entrance of intersecting roads, and on the hard shoulder within the plus or minus 15 deg sweep of the radar beam.

The radar only detected and located objects; it could not determine their size. When the vehicle and an object ahead were on a collision course (because the object was in the path of the driver's vehicle and was either stationary or had a slower velocity than the driver's vehicle), the DAS displayed a white rectangular outline at that location if the vehicle's speed was less than 70 mph. When the vehicle was 3 seconds away from the object ahead, the rectangular outline changed from white to red; if the object was in the vehicle's path, the driver needed to take immediate action. If the speed was 70 mph or greater at the time of detection (a speed that the ambulance or patrol car might frequently reach in operation), the rectangle would already be red when it appeared and would not change color.

For safety reasons, the outline was the width of a truck – the widest vehicle that was likely to be encountered, as a worst-case possibility. When the vehicle was 3 seconds driving time away from the threatening object, the driver got the collision warning, in which the rectangular outline changed from white to red. If that occurred and the object remained in the vehicle's path, the driver needed to take immediate corrective action. Even in poor visibility, the driver would usually be able to get close enough to visually identify the object.

Side-looking Sensor and Collision Avoidance

The side-looking sensors consisted of four 10GHz radar sensors each for the snowplows or two 10GHz radar sensors each for the ambulance and patrol car. These collision detection sensors were manufactured by Altra Technologies. Though the sensors could detect objects up to 25 feet away, they are proximity detectors. That means that they did not detect specific range or range rate, only presence, although they had a close alarm (0 to 4 feet) and far alarm (4 to 12 feet).

The visual side collision avoidance warning was via a pair of Altra Technologies LED displays mounted on the roof posts inside the cab. The side collision warning was activated if an object was within the side sensor field of view and the driver had activated the turn signal for that side. This warning was provided to the driver with the red LEDs. A side collision advisory was activated via the amber LEDs if a vehicle was located within the side sensor field of view and the turn signal was not on.

Vehicle Data Acquisition System (vehDAQ)

The vehDAQ was made up of computer components and peripheral components, such as cameras (described below) and microphones. The vehDAQ was triggered by the DGPS signal; that is, when the vehicle was determined to be on the test corridor, the vehDAQ was activated. Engineering unit data (i.e., vehicle location determined by DGPS and magnetic tape, acceleration from the IMU, etc.) was provided from the vehicle main computer via an ethernet connection; this eliminated duplication of sensors and signal processing equipment. The vehDAQ had a removable hard drive from which engineering unit data and video data were downloaded. These hard drives and their data were handled per a chain of custody.

Cameras

The vehDAQ utilized four cameras per specialty vehicle. One of these, a forward-looking high-resolution color cameras was aimed so as to record the view forward out of the windshield; it was a much higher quality camera than the other cameras that were used to record driver behavior. This forward-looking camera recorded what the driver was seeing as well as data necessary to compute the visibility. The remaining three cameras - which were used to record driver behavior - view the driver's face, hands, and feet, respectively. The vehDAQ also made an audio record while the system is running.

2.1.6 Visibility and Weather Stations

Visibility was measured by the forward-looking camera described above, plus roadside weather stations. At evenly-spaced locations along Highway 7 between I-494 and Hutchinson, six new sensors capable of measuring visibility were installed for the purposes of the FOT. Of these six sensors, one was augmented with sensors to provide additional information on atmospheric conditions. One field station of Mn/DOT's Road/Weather Information System (R/WIS) was already located on the test corridor and it complemented the six new sensors. The information coming from the R/WIS site included data on pavement conditions. Therefore, the sensor system not only determined visibility at seven discrete locations, but also provided information regarding what weather conditions contributed to reduced motorist visibility.

2.1.7 Detailed Design Document

For more specific information about the IVI systems, consult the Detailed Design, Intelligent Vehicle Initiative Specialty Vehicle Field Operational Test, August 2001, submitted under task 3.5 of the Mn/DOT – US DOT Cooperative Agreement.

2.2 Research Plan

This subsection describes the FOT research plan that was utilized by the Mn/DOT Partners. It describes the Mn/DOT Partners' overall approach, including operation of the specialty vehicles, and the roadways designated for the test (including maps). Also presented is a detailed discussion of the experimental design that was developed in collaboration between the Mn/DOT Partners and Battelle as the Independent Evaluator.

2.2.1 Overview of Mn/DOT FOT Research Plan

During the FOT, the 6 test vehicles operated on their usual state and county highway routes. Part of those routes were prepared and designated as test roads or control roads (see below for a more detailed description of both). The primary test road for the FOT was a 45-mile section of Minnesota Trunk Highway 7 (TH-7) that runs generally east-west between the I-494 beltway in Minnetonka (a community on the western side of Minneapolis) and the City of Hutchinson. There was also a 4-mile section of (McLeod) County Road 7 extending northeast from Hutchinson that was included in the FOT under state funding. Figure 2-2 is a map of the County Road 7 test section. Figure 2-3 is a map of TH-7 and County Road 7 with geographical characteristics. Figure 2-4 shows the specialty vehicle operating areas. Also shown in Figure 2-3 and 2-4 are the control road segments described below.

The vehicles used in the FOT consisted of:

- Four (4) Snowplows, all instrumented with DAS (Driver Assistive System) plus forward- and side-looking radar to collect driver performance data, and
- One (1) ambulance and one (1) state patrol vehicle, both instrumented with DAS plus forward- and side-looking radar.

The 3 Mn/DOT snowplows operated in the Eden Prairie, Shakopee, and Hutchinson sub-areas respectively from east to west along the TH-7 part of the test corridor. Each Mn/DOT snowplow cleared a section that was roughly one-third of the length of the TH-7 test corridor (see Figure 2-4). Along the test corridor, the geography, road characteristics, traffic, and population densities varied. The Hutchinson and McLeod County snowplows operated out of the same facility – the Hutchinson Area Transportation Services (HATS) garage – and experienced the same weather, although the characteristics of their routes were somewhat different. There was some variation in the snowplows' operations and assignment (see Figure 2-3). The ambulance and patrol car had more variety in their routes. During the FOT, each vehicle was operated on the same route(s) under the same operational deployment as it did prior to the FOT.

Disabling the DAS by disconnecting the driver interface, from the driver's standpoint, essentially restored the vehicle to its original operating characteristics. And an instrumented vehicle's DAS was automatically deactivated whenever it departed the TH-7 test corridor. Thus, a driver departing the corridor saw the virtual lines on the HUD end ahead of the vehicle, while a driver entering the corridor saw the virtual lines begin ahead of the vehicle.

Magnetic tape was installed on a 4-mile section of County Road 7 north of Hutchinson and the westernmost 8 miles of TH-7, between Hutchinson and Silver Lake. Figures 2-2, 2-4 and 2-5 illustrate those sections with magnetic tape. The 45-mile TH-7 and 4-mile County Road 7 sections both received full differential global positioning system (DGPS) mapping that included the locations of roadway edge lines and center lines and "roadside furniture" such as mailboxes, guardrails, and jersey walls.

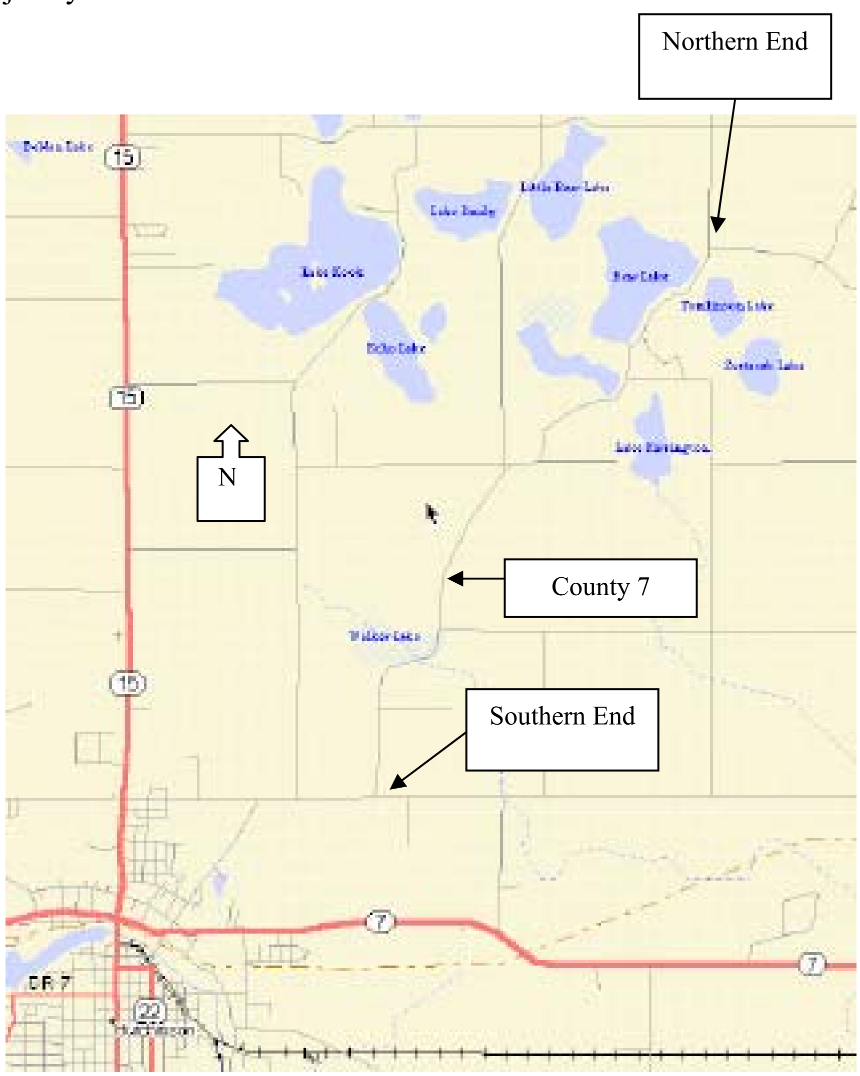
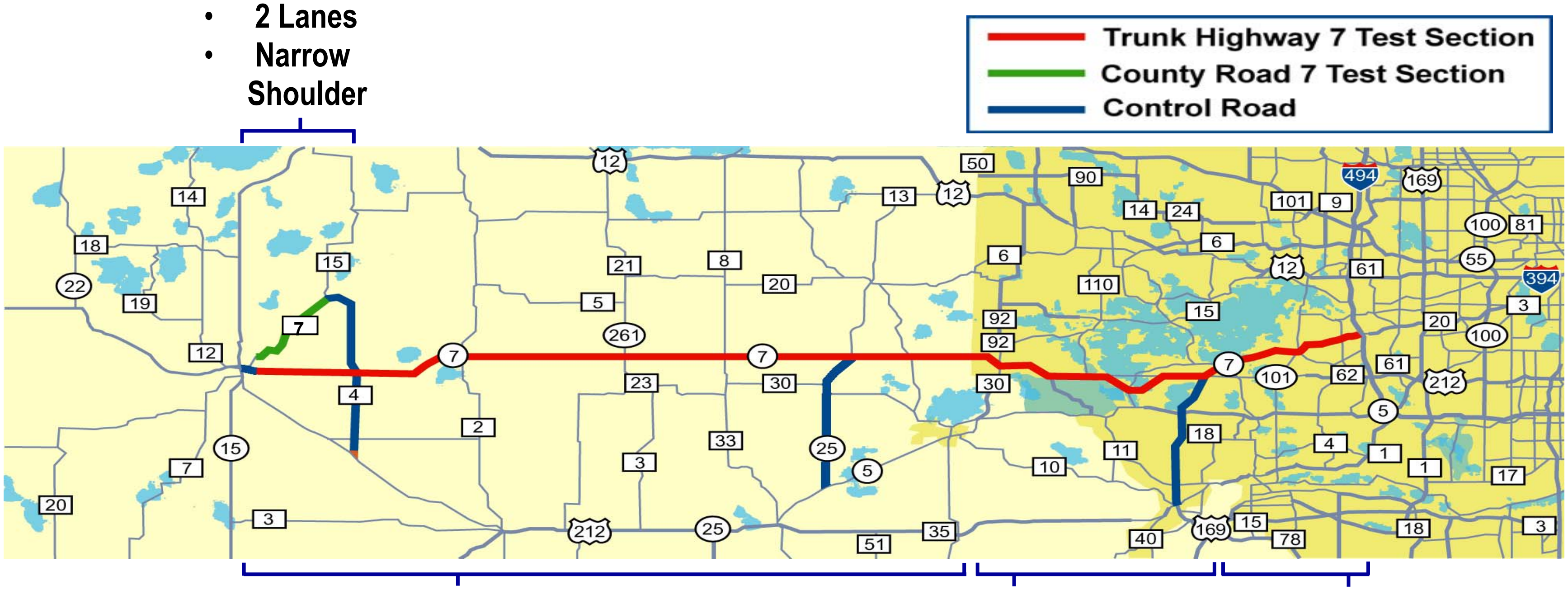


Figure 2-2. McLeod County 7 Roadway

County Road 7
- Curvy
- 2 Lanes
- Narrow Shoulder



- Flat, Straight
- 2 Lanes Plus Some Turn Lanes
- Wide Shoulders

- Curvy, Hilly
- 2 Lanes
- Wide Shoulders
- Canyons and Vegetation

- 4 Lanes, Jersey Wall
- Full Shoulder
- Suburban
- Heaviest Traffic

Winter storms from northwest across flat land produce worst visibility and driving conditions

Figure 2-3. FOT Test Roads and Control Roads

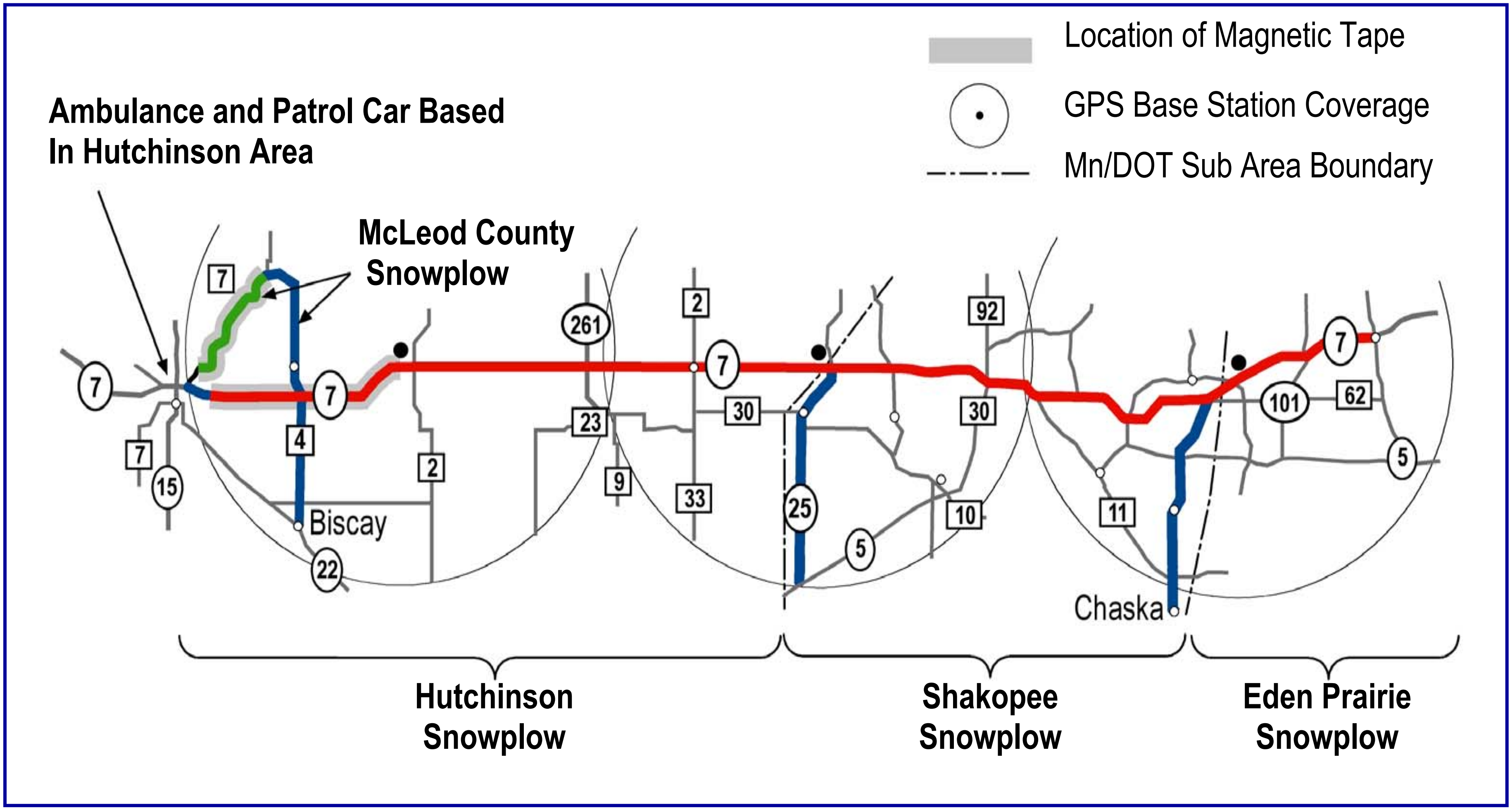


Figure 2-4. Specialty Vehicle Operating Areas

Figure 2.5 shows the location of the 8-mile long section at the western end of TH-7 on which magnetic tape was installed on lane markings.

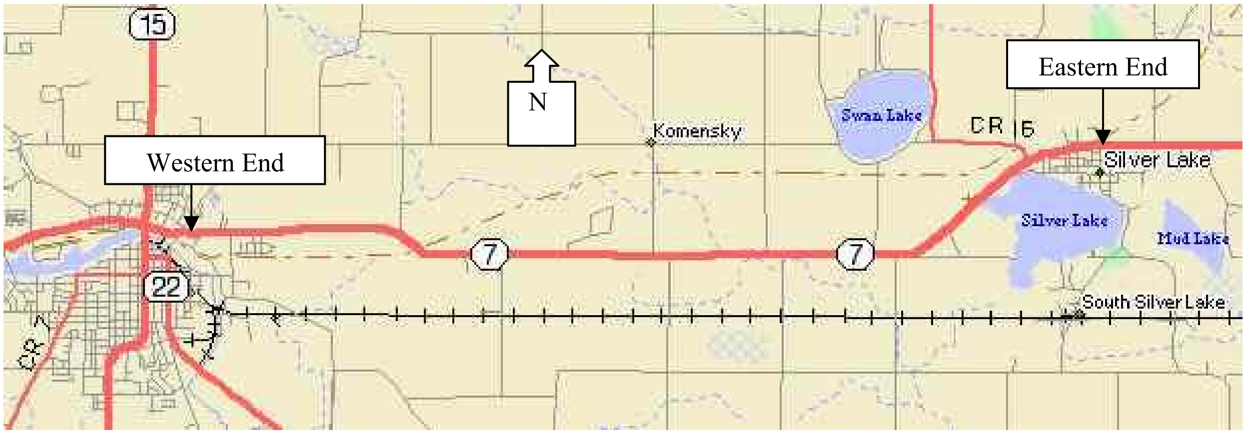


Figure 2-5. Trunk Highway 7 Corridor Between Hutchinson & Silver Lake, where Lanes were Defined by Magnetic Tape Along an 8-Mile Section

2.2.2 Proposed Experimental Design

The research plan for this FOT was designed to support experimental comparisons between instrumented specialty vehicles performing controlled testing within the test corridor. The field testing of the vehicles' IVSS was intended to occur on state and county highways under low-visibility conditions such as snow, blowing snow, fog, and nighttime driving.

Control Roads Approach

Mn/DOT and the University of Minnesota decided to fully instrument all specialty vehicles with IVSS and driver interfaces. They felt that this was necessary to maximize the amount of data collected with active driver interfaces. Later, recognizing the need for a greater volume of data, they formulated the idea of using "control roads" to collect certain control data. In addition to the test corridor routes, there were several designated control road sections associated with the TH-7 corridor and County Road 7. When a snowplow was off the test corridor and on a control road, its driver interface would be automatically turned off but its vehDAQ would still collect limited data on the partially-mapped control road segment. Specifically, the control roads were:

- Sections of state or county roads adjacent to TH-7 or County Road 7 on snowplows' regular routes,
- Traveled occasionally by ambulance and patrol car (except Hwy 41),
- Within range for DGPS correction signal processing,
- Not equipped with magnetic tape, not mapped for roadside furniture, and
- Centerline mapped, lane and shoulder width classified.

These control roads were basically similar in features to the adjacent test road in their area. The control roads were partially DGPS-mapped so that they could allow additional data to be collected on lane-keeping. They were generally away from built-up areas, so that the effect of streetlights that could improve visibility would be minimal. Figures 2-3 and 2-4 above show the locations of the control roads.

The McLeod County snowplow control road included County Road 4 from the northern end of the County Road 7 test section south to TH-7. Originally, that control road was intended to cross TH-7 onto State Highway 22 for a total of about 10 miles, but no driving data were received for that section (which accounted for about half of those 10 miles). Likewise, there was an intended control road on the Hutchinson snowplow route, which was the short extension of TH-7 from the western end of the magnetic tape westward toward the intersection with State Highway 15, but no driving data were received for that stretch.

The Shakopee snowplow control roads included State Highway 25 from TH-7 south to the intersection with State Highway 5, a distance of approximately 8 miles; and State Highway 41 from TH-7 south through the town of Chaska to the Mn/DOT garage, a distance of about 9 miles (but driving data were received for only a fraction of that distance, less than 3 miles). Eden Prairie did not have a snowplow control road, largely due to FCC restrictions on the DGPS frequency range on the plow route east of I-494.

However, with the control roads approach there were some differences in the types of data to be collected on the control roads and test roads. On the test corridor (TH-7 and County Road 7), the GPS coordinates of the lane edge lines and roadside furniture were mapped and 12 miles total of the test corridor in its western end had magnetic tape. Because the control roads were off the TH-7 / County Road 7 test corridor, the DAS was not available (which meant the forward-looking radar collision avoidance system was not available) nor was magnetic lateral guidance. Only partial driving data (unfiltered forward radar data, GPS, vehicle data) were received, with no identification of roadside objects. But DGPS would allow some lane-keeping performance of a vehicle on these roads to be analyzed. This approach was intended to maximize the overall data collection.

Even though the control roads were primarily meant for gathering data on the snowplows that removed snow from them, the ambulance and state patrol car occasionally traveled the control roads (except the State Highway 41 section) in response to emergencies or other situations. Data were meant to be collected on all instrumented specialty vehicles that traveled these control roads as part of the FOT. Since the control roads generally ran north-south, the ability to get a DGPS correction signal was diminished the farther a control road extended from TH-7. Thus, the length of some of the control roads (particularly the State Highway 25 and 41 sections) was partly constrained by the quality of the DGPS correction signal. Signal quality was also diminished by geographical irregularities and by foliage such as tree canopy.

Table 2-1 below displays the overall availability of IVSS technologies that were in the experimental design for each instrumented specialty vehicle in the FOT.

Table 2-1. Availability of IVSS Technologies in the Experimental Design for Each FOT Specialty Vehicle

TEST VEHICLE	VEHICLE OPERATING LOCATIONS	Availability of IVSS Technologies			
		Magnetic Lateral Guidance	DGPS Guidance Lane-keeping Performance	Collision Warning/ Avoidance	Vehicle Data Acquisition System (vehDAQ)
HUTCHINSON SNOWPLOW	Western section of TH-7 test corridor and short control road section of TH-7	Available on 8.0-mile section of TH-7 between Silver Lake and Hutchinson	Can determine performance on TH-7 test corridor and control road	ON while on test corridor, OFF when on control road	ON
MCLEOD COUNTY SNOWPLOW	County Road 7 test section northeast of Hutchinson plus County Road 4 control road	Available on 4.3-mile test section of County Road 7 northeast of Hutchinson	Can determine performance on County Road 7 test section and on control road except when DAS deactivated for controlled test	ON while on test corridor, OFF when on control road	ON
SHAKOPEE SNOWPLOW	Central section of TH-7 test corridor plus State Hwy 25 and 41 control roads	Not available on snowplow route	Can determine performance on TH-7 test corridor and on control roads	ON while on test corridor, OFF when on control roads	ON
EDEN PRAIRIE SNOWPLOW	Eastern section of TH-7 test corridor	Not available on snowplow route	Can determine performance on TH-7 test corridor only except when DAS deactivated for controlled test	ON while on test corridor, otherwise OFF (no control road)	ON
STATE PATROL SQUAD CAR	On and off of the test corridor, primarily in the western part	Available on 8.0-mile section of TH-7 between Silver Lake and Hutchinson and on 4-mile section of County Road 7	Can determine performance on TH-7 test corridor, County Road 7 section, and control roads	ON while on test corridor, OFF when on control roads	ON
HUTCHINSON AMBULANCE	On and off of test corridor, primarily in the western part, and makes routine trips along entire length of TH-7 corridor	Available on 8.0-mile section of TH-7 between Silver Lake and Hutchinson and on 4-mile section of County Road 7	Can determine performance on TH-7 test corridor, county Road 7 test section, and control roads	ON while on test corridor, OFF when on control roads	ON

Data collection was scheduled to take place from the first low-visibility conditions, which were originally expected to occur during the November 2001 to May 2002 timeframe. These data were to be reduced and analyzed by Battelle to assess the benefits of the IVI devices described in the above systems. Figure 2-6 shows the planned and actual schedules for operator training, Beta testing, and field controlled testing of the IVSS.

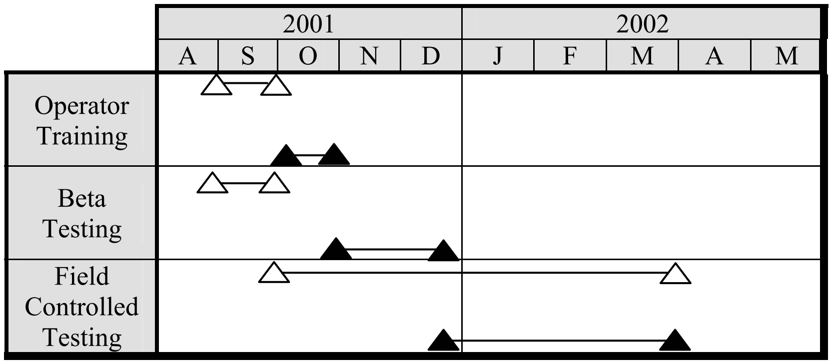


Figure 2-6. Planned and Actual FOT Test Schedules

Control Time Approach

Battelle's safety benefits estimation methodology was predicated upon using various types of driving data in order to predict the number of crashes that might be avoided if all such vehicles were equipped with IVSS technologies. For certain types of crashes, such as rear-end collisions, it was acceptable to collect control and test data on different roads, as long as they had similar characteristics. However, in order to evaluate the benefits of vision enhancement systems for avoiding roadway departure crashes, it appeared necessary to collect at least <u>some</u> driving data on the same road, both with and without the systems. In addition to the "control road" design proposed by Mn/DOT and the University of Minnesota, Battelle needed drivers to operate some of the fully-instrumented specialty vehicles on the test corridor with the driver display systems on for part of the time and off the rest of the time. This aspect of the experimental design was referred to as the "control time" design.

Battelle desired an approach that used a combination of the control road and control time designs. One of the concerns over using the "control road" design alone was that the control roads might differ from the test roads in some important ways. These differences included drivers' experience on the roads, direction of the roads, types of shoulders, elevation changes and curves, and the amount of traffic. For certain type of analyses it was sufficient to collect driving data on control and test roads that were "similar." In those cases, the data comparisons were not location-specific. For example, the analyses of general driving behaviors (e.g., average plowing speed, lane keeping ability), and incidence of rear-end lane change/merge crashes did not require comparisons of data collected on the same road.

However, to estimate the reduction in single vehicle roadway departure (SVRD) crashes, it was important to collect data on how close the vehicles came to the same fixed roadside objects, both with and without the aid of IVSS. It would have been virtually impossible to conduct this type of "paired-comparison" with data from different roadways. This would have been particularly true when evaluating the benefits of vision enhancement systems, because driving behaviors had to be compared among road segments that were visually the same. These data would have been used to estimate the probability of specific driving conflicts leading to SVRDs, as well as the probability of a crash following such a conflict. These probabilities needed to be estimated for snowplows in particular, both with and without active vision enhancement systems.

Implementing the "control time" approach required a strategy for turning the driver interfaces on and off. In most cases, a statistically optimal design would assign half the experimental units to the control group and half to the test group. In the Mn/DOT FOT, this would mean running the vehicles with the driver interfaces active for half the time on the test corridor and inactive for the other half. However, there were legitimate concerns over collecting sufficient data with an active system during adverse weather conditions. While the "50-50" approach was feasible if there were abundant adverse winter weather, it could reduce already limited data if low snowfall occurred (which in fact was the case in the 2001-2002 winter). Nighttime and fog were themselves low-visibility conditions but would not suffice to test the full capabilities of the IVSS. Inopportune winter conditions (i.e., lack of snow and low visibility conditions) had already lessened the expected results from some earlier prototype studies on these technologies in Minnesota.

Two approaches for activating the driver interfaces were considered. One was based on weather conditions and the other based on the calendar. Since the weather-based approach was deemed to be too complicated with little or no advantage, the calendar-based approach was recommended. Because some data would be available from vehicles operating on the control roads, and there were legitimate concerns over collecting sufficient data with an active system during adverse weather conditions, Battelle proposed that the driver interfaces be turned off one-third of the time while the plows were on the test corridor. The schedule that was initially discussed with the University of Minnesota and proposed for the four snowplows and the patrol car is presented in Table 2-2.

Battelle recommended reviewing the design after 14 weeks of data collection to consider possible modifications. For example, if we were experiencing an unusually mild winter the design could have been changed to include more data collection with active driver interfaces. This would have helped ensure sufficient data for other types of analyses, which did not require location specific data.

It was important to consider the drivers' reactions to the proposed experimental design. We recognized that it might have been disruptive to turn the system on and off; but we believed that if the drivers were informed about the reasons for this approach, they would accept the approach. In fact, it may have helped them articulate the advantages and disadvantages of the systems during the interviews if they were able to correlate their feelings about driving conditions and behaviors with whether or not the system was active. Thus, in addition to satisfying the data needs for Battelle's safety benefits estimation methodology, this design could have had benefits in human factors analysis. Data collected in the driver interviews and questionnaires were more likely to reflect the drivers' true feelings about the IVSS technologies because the effects of weather and roads would not have been confounded with the effectiveness of the system.

Table 2-2. Snowplow and Patrol Car Design Schedule

	McLeod Co. Snowplow	Hutchinson Snowplow	Eden Prairie Snowplow	Shakopee Snowplow	Patrol Car
Week 1	On	On	On	Off	Off
Week 2	On	On	Off	On	On
Week 3	Off	Off	On	On	On
Week 4	On	On	On	Off	Off
Week 5	On	On	Off	On	On
Week 6	Off	Off	On	On	On
Week 7	On	On	On	Off	Off
Week 8	On	On	Off	On	On
Week 9	Off	Off	On	On	On
Week 10	On	On	On	Off	Off
Week 11	On	On	Off	On	On
Week 12	Off	Off	On	On	On
Week 13	On	On	On	Off	Off
Week 14	On	On	Off	On	On
Week 15*	Off	Off	On	On	On
Week 16	On	On	On	Off	Off
Week 17	On	On	Off	On	On
Week 18	Off	Off	On	On	On
Week 19	On	On	On	Off	Off
Week 20	On	On	Off	On	On
Week 21	Off	Off	On	On	On
Week 22	On	On	On	Off	Off
Week 23	On	On	Off	On	On
Week 24	Off	Off	On	On	On
Week 25	On	On	On	Off	Off
Week 26	On	On	Off	On	On
Week 27	Off	Off	On	On	On
Week 28	On	On	On	Off	Off

* Date to consider possible design modifications.

It was recognized that the ambulance may have been driven by up to 15 different drivers. With the recommended design, the driver interface in the ambulance would have been active on the test corridor and inactive on the control roads. We did not recommend implementing the "control time" design for the ambulance because, with that many drivers, there would not have been enough data to do meaningful comparisons at specific locations. However, the existing design had some distinct advantages for the human factors analysis because of the large number of drivers with driving experience on both equipped and unequipped vehicles.

Revised Approach

Battelle and the University of Minnesota discussed and negotiated an alternate plan that incorporated changes to the experimental design, and this proposed experimental design schedule was shared with Mn/DOT. This plan called for all of the vehicles' driver interfaces to be turned on at the start of the FOT. This would allow all last-minute "bugs" to be worked out of the system. These data would be transferred to Battelle within a week of being collected. Battelle would store and use these data to start identifying driving conflicts and exercising their analysis models. After all issues with the collection and transfer of the data to Battelle had been resolved, and after Battelle had had time to start analyzing the data, we would have arranged some driver interface off time.

This proposed schedule specified that the driver interfaces would be active for two weeks, then turned off for one week starting at the first anticipated snow date. To ensure that both control data and test data were collected for all weather events, at least one snowplow would have active interfaces and at least one would have the interfaces turned off at any given time. Driver interfaces would not have been turned off until at least three severe snow events had occurred – but no sooner than four weeks. This would have allowed the drivers to become more familiar with the systems and allowed the systems to be tailored to individual drivers, if necessary. The definition of severe snow event was necessarily vague and included a requirement for low-visibility conditions. Within this plan, a designated senior Mn/DOT snowplow driver who was a key person in the management of the FOT would have made this determination of a severe snow event here and in other areas of the design strategy where needed.

Once there had been three severe snow events for the Eden Prairie snowplow, its driver interfaces would have been turned off. Similarly, the McLeod County snowplow's driver interfaces would have been turned off after it experienced three severe snow events. Depending on local weather conditions, the Eden Prairie and McLeod County snowplows may not have necessarily been on the same schedule. The driver interfaces would have remained off for a minimum of three weeks and until at least two severe snow events had occurred, at which point they would have been turned on again. (By this scheme, neither the Shakopee and Hutchinson snowplows nor the ambulance and patrol car would have had their driver interfaces turned off during the FOT.)

Battelle would have analyzed the data collected up to this point and made an assessment of how our methodology was working, and would have then recommended how the design should proceed. If the methodology showed promise, we would have recommended that the same two snowplows (Eden Prairie and McLeod County) follow a schedule of driver interface on and off time. The schedule would have been to switch the driver interface status every three weeks. If the drivers were using the system only in very severe conditions, then the design might have been revised so that the driver interface status was dependent on weather events. (As mentioned earlier, the two snowplows' schedules may have differed in accordance with local weather conditions.) For example, the three weeks on and three weeks off schedule could have been maintained unless there were no severe weather events during a three-week period, in which case, the system would have retained its current status until a severe weather event was observed. Again, John Scharffbillig would have made this determination. If Battelle determined that our

SVRD methodology could not be successfully applied to these data, then the driver interfaces would have remained active for the remainder of the winter.

Outcome of Proposed Experimental Design

Ultimately, there were not enough adverse weather events during the FOT to consider implementing this approach. With the very limited low-visibility conditions that were experienced, it was important for the University of Minnesota to capture all possible data while the vehicles were operating. Battelle understood and supported that outcome. None of the vehicles operated per the revised "control time" approach. However, the result was that Battelle was not able to get comparative results as desired.

2.3 Operational Characteristics Affecting the FOT

There were two major problems that affected the FOT. The first was the weather conditions experienced. The second was a technical problem with the DGPS, explained below.

DGPS Problem

There were problems resulting from geographical irregularities interfering with the DGPS correction signal, particularly around the area of St. Bonifacius, which was identified early in the FOT as the area along TH-7 that would pose the greatest challenge to the DGPS signal reception. During the FOT, that area was in fact subject to dead zones of DGPS coverage. Also, in the vicinity of Bear Lake near the northernmost end of the County Road 4 test section, there was a location where the DGPS signal was sometimes lost. This loss was attributed to a particular stand of trees.

According to Mn/DOT's *Preliminary Results of Field Operational Test (conducted December 2001- March 2002)*, a DGPS problem grew from difficulties that the original GPS receivers had in transitioning between DGPS base stations. Switching between base stations was supposed to be automatic and not result in loss of the desired 2 cm positioning accuracy. The GPS receivers from the original manufacturer that were on the vehicles were unable to make the transition, degrading positional accuracies beyond what was sufficient for lane-keeping. The problem was resolved by replacing the receivers with another make, but by then the problem had imposed a significant delay on beginning the active period of the FOT. The Mn/DOT FOT project management reported that the delay had collateral effects on two key aspects of the program.

First, a shakedown of the system could not be performed because accurate GPS measurements were unavailable until late in the test period. Second, the consequent delays in releasing the test vehicles until the GPS problem was corrected caused delays of three months between classroom and in-vehicle training. So rather than operating the vehicles based upon training information that was just a few days or weeks old, the drivers instead had to rely on training that had occurred much earlier. The first substantial snowfall during the FOT period occurred on March 8, which meant that 5 months passed between the classroom training and when most of the drivers were first able to operate the IVSS in adverse weather.

Weather

The research plan discussion (Section 2.2) emphasized the importance of having sufficient snow accompanied by low visibility conditions to completely achieve the goals and objectives of the evaluation. Those conditions were necessary both for the objectives of the Mn/DOT Partners' Field Operational Test as well as its independent evaluation by Battelle. However, the winter of 2001-2002 in the area of the test corridor turned out to be unusually warm and relatively devoid of snow. During the period of the FOT - December 21, 2001 – March 31, 2002 – there were only two snowfalls of significance, which occurred on March 8-9 and March 14-15.

Mn/DOT FOT project management reported that the winter of 2001-2002 was one of the mildest on record in Minnesota. They noted that visibility data indicate that there was no occasion during the FOT in which the visibility was very low (defined as less than 100 meters). There were only 15 minutes during the FOT when visibility was in the 100 to 199 meter range, and no specialty vehicle operators were driving at that time. There were only very limited periods when visibility was in the 200 to 299 meter range. One meteorological site held that visibility for 110 minutes but no specialty vehicles operators were in the vicinity and so did not experience those conditions. Thus, in the words of Mn/DOT FOT management: "at no time were any of the specialty vehicle operators exposed for sustained periods to the kind of conditions for which the Driver Assistive System was designed."

3.0 EVALUATION GOALS

This section defines the goals and objectives that guided the development of the evaluation plan for the Mn/DOT Partnership Intelligent Vehicle Initiative (IVI) Generation 0 Field Operational Test (FOT). Section 3.1 describes the original goal areas and how they were prioritized to achieve national IVI goals while meeting the needs of the IVI FOT partners. Objectives are presented for each goal area in Section 3.2 and specific hypotheses/research questions are provided to suggest the types of data that would be needed during the FOT.

Because of the unusually mild winter experienced in 2001-2002, it was not possible to test the IVSS technologies under the low visibility conditions for which they were designed. Thus, several of the evaluation goals and objectives could not be addressed at all and others could not be addressed in the manner described in this plan. Section 3.3 describes the extent to which each of the goals and objectives was met during the abbreviated FOT and discusses how various factors affected our evaluation plans. Additional information on the work accomplished, including descriptions of the data collected and partial analysis results, are presented in Sections 5, 6 and 7.

Definitions and examples of key terms used in this section of the document are presented below.

Definition and Examples of Goal Areas, Objectives, Hypotheses, and Measures

Goal Area – Broad area of benefits, impacts, or factors to be evaluated.

- **Example: Assess Safety Benefits**

Objective – Specific type of information to be obtained within a goal area.

- **Example: Determine if drivers drive more safely with intelligent vehicle safety systems (IVSS).**

Hypothesis – A specific statement, related to an objective, which is to be tested using data and analyses. Sometimes hypotheses are stated in the form of Research Questions.

- **Example hypothesis: Drivers using a collision warning system (CWS) will maintain greater following distances from lead vehicles than drivers without CWS.**

Measure – A variable or parameter used to test hypotheses.

- **Example: Expected number of rear-end crashes (derived from analysis)**
- **Example: Number of times a vehicle's following distance is less than a safe following distance threshold (a surrogate measure used to derive the expected number of rear-end crashes).**

3.1 Process of Establishing and Prioritizing Evaluation Goals

The U.S. DOT suggested five goal areas along with some generic objectives for each goal. These objectives were to be tailored to meet the needs of each IVI FOT. The first evaluation goal is as follows:

Goal 1: Achieve an In-depth Understanding of the Benefits of IVI Technologies

Because the benefits of the IVI technologies fall into four different categories (safety, mobility, efficiency, and productivity), this goal area is divided in four separate goals, labeled 1A-1D, each corresponding to a different benefit category. The remaining goal areas are as follows:

Goal 2: Assess Impacts on Driver Acceptance

This rewording of Goal 2 (compared to the wording in the DOT Prospectus) reflects the focus on human factor issues. Evaluation of driver performance (in particular, answers to the question "Do drivers drive more safely with IVI?") are considered under Goal 1A – Safety Benefits.

Goal 3: Assess System Performance

Goal 4: Assess Product Maturity for Deployment

Goal 5: Address Institutional and Legal Issues that might Impact Deployment

These goals were first discussed with the Mn/DOT partners and the U.S. DOT during an Evaluation Workshop on December 8, 1999. The purpose of this workshop was to: (1) provide participants and stakeholders in the Mn/DOT IVI Operational Test with a preliminary framework for the evaluation and (2) obtain their thoughts and inputs on specific evaluation goals, measures, and data collection methods. The Evaluation Workshop was hosted by Mn/DOT and was planned and conducted by Battelle. Notes from the meeting, a list of attendees, and breakout group summaries were compiled by Battelle and distributed after the meeting.

Overall goals for the effort were discussed and interpreted during the workshop and priorities were established by polling the participants. Within each goal area, a number of specific objectives and hypotheses were proposed. To help define the scope and priorities of the evaluation project, participants were asked to assign priority points (out of a total of 100 points) to each of the proposed goal areas based on several factors, including the perceived importance of the goal, feasibility of achieving the goal, and the resources required to obtain useful evaluation data during the FOT. The priority ratings established during the workshop are shown in Table 3-1.

Table 3-1. Priorities of Mn/DOT FOT Evaluation Goals by Group

	ADMINISTRATION	OPERATIONS	DRIVERS
Safety	30%	45%	41%
Mobility (Public, Emergency Services, Freight)	22%		
Public Perception	9%	12%	3%
Productivity/Efficiency	20%	21%	27%
Cost	10%	22%	14%
Institutional	9%		
Job Satisfaction			15%
TOTAL	100%	100%	100%

Since the workshop, further discussions with the Mn/DOT and the U.S. DOT have helped to clarify and refine the evaluation objectives. At the time the evaluation plan was developed, there was no indication that the relative priority of these goals had changed.

3.2 FOT Goals, Objectives, and Measures

This section describes each of the goal areas and presents specific objectives and supporting hypotheses/research questions that motivated and guided the planned evaluation approach. These are the original goals and objectives that were established through a consensus process with the FOT partners and U.S. DOT. Together with the priorities established during this planning process, the goals and objectives presented below were used to motivate the planned approach described in the remainder of this document, even thought many of the goals and objectives could not be met during the abbreviated FOT. In developing this approach we considered the relevance of proposed FOT data for achieving the specific goals, the relative priorities of the goals, and the evaluation resources that were available. The USDOT requested that the evaluation emphasize the safety evaluation as the highest priority.

Goal 1A. Achieve an In-Depth Understanding of Safety Benefits
The primary safety benefit expected from the deployment of the IVI technologies is a reduction in the number and severity of snowplow, patrol car, and ambulance crashes and the resulting injuries and fatalities. Also, the Rear-guard/External Light Warning System has the potential to reduce incidents involving public vehicles crashing into the rear of snowplows. This goal area is divided into four objectives.

Objective 1A.1 Determine whether drivers drive more safely with the IVI technologies than without them.

The IVI technologies will warn drivers of unforeseen hazards and of potential lane deviations. The systems have the potential to improve overall driving performance. Detailed analysis of objective and subjective FOT data will be required. The principal evaluation data source related to this objective is onboard driving data. Supplemental data sources are historical & FOT crash/incident data, surveys & interviews, and operations records. Specific questions to be addressed include:

1A.1-1 Will the IVI technologies reduce the overall number of near-misses involving a snowplow?

- A. Single Vehicle Roadway Departures (SVRD) near-misses by snowplows during low visibility?
- B. Near-misses in which a snowplow nearly rear-ends another vehicle during low visibility conditions?
- C. Near-misses in which another vehicle unaware of the snowplow's presence nearly rear-ends the snowplow during low visibility conditions?
- D. Lane change/merge near-misses involving a snowplow and another vehicle of whose presence the snowplow is unaware?

1A.1-2 Will the IVI technologies reduce the overall number of near-misses involving a patrol car?

- A. SVRD near-misses by patrol cars during low visibility conditions?
- B. Near-misses in which a patrol car nearly rear-ends another vehicle during low visibility conditions?
- C. Near-misses in which another vehicle unaware of the patrol car's presence nearly rear-ends the patrol car during low visibility conditions?
- D. Lane change/merge near-misses involving a patrol car and another vehicle of whose presence the patrol car is unaware?

1A.1-3 Will the IVI technologies reduce the overall number of near-misses involving an ambulance?

- A. SVRD near-misses by ambulances during low visibility?
- B. Near-misses in which an ambulance nearly rear-ends another vehicle during low visibility conditions?
- C. Near-misses in which another vehicle unaware of the ambulance's presence nearly rear-ends the ambulance during low visibility conditions?
- D. Lane change/merge near-misses involving an ambulance and another vehicle of whose presence the ambulance is unaware?

1A.1-4 How do the IVI technologies affect driver lane-keeping behavior?

1A.1-5 How do the IVI technologies improve driver ability to detect lane edges and/or forward obstacles and allow more clearance?

1A.1-6 How do the IVI technologies affect vehicle headway?

1A.1-7 What is the impact of the IVI technologies on driver braking behavior?

1A.1-8 How do the IVI technologies affect the speed of the vehicles?

1A.1-9 What is the impact of the IVI technologies on driver reaction times?

1A.1-10 How do the IVI technologies affect driver risk-taking (e.g., following behaviors) and decision making?

Objective 1A.2 Determine whether vehicles with IVI technologies will have fewer crashes than vehicles without the system.

Improvements in driving behavior (driving more safely), advance warnings of potential dangers, and improved performance are expected to result in fewer crashes. This objective focuses on the relationship between driving behavior and crashes under conditions that are encountered under the FOT. Detailed analysis of objective FOT data will be required. The principal evaluation data sources related to this objective are historical & FOT crash/incident data and onboard driving data. Specific questions to be addressed include:

1A.2-1 Will the IVI technologies reduce the overall number of crashes involving a snowplow?
- A. SVRD crashes by snowplows during low visibility?
- B. Crashes in which a snowplow nearly rear-ends another vehicle during low visibility conditions?
- C. Crashes in which another vehicle unaware of the snowplow's presence nearly rear-ends the snowplow during low visibility conditions?
- D. Lane change/merge crashes involving a snowplow and another vehicle of whose presence the snowplow is unaware?

1A.2-2 Will the IVI technologies reduce the overall number of crashes involving a patrol car?
- A. SVRD crashes by patrol cars during low visibility conditions?
- B. Crashes in which a patrol car nearly rear-ends another vehicle during low visibility conditions?
- C. Crashes in which another vehicle unaware of the patrol car's presence nearly rear-ends the patrol car during low visibility conditions?
- D. Lane change/merge crashes involving a patrol car and another vehicle of whose presence the patrol car is unaware?

1A.2-3 Will the IVI technologies reduce the overall number of crashes involving an ambulance?
- A. SVRD crashes by ambulances during low visibility?
- B. Crashes in which an ambulance nearly rear-ends another vehicle during low visibility conditions?
- C. Crashes in which another vehicle unaware of the ambulance's presence nearly rear-ends the ambulance during low visibility conditions?

D. Lane change/merge crashes involving an ambulance and another vehicle of whose presence the ambulance is unaware?

1A.2-4 Will the IVI technologies result in fewer injury accidents and fatalities for snowplow, patrol car, and ambulance operators/passengers?

Objective 1A.3 Determine the number of crashes, injuries, and fatalities that could be avoided if all snowplows, patrol cars, and ambulances in the United States that operate in areas of reduced visibility were equipped with IVI technologies.

This objective focuses on extrapolating the results observed in the FOT to predict crash, injury, fatality reductions, and property damage for applicable regions of the entire nation. This requires an assessment of the potential impact of driver experience and vehicle characteristics on the effectiveness of the IVI technologies. Detailed analysis of objective FOT data will be required. The principal evaluation data sources related to this objective are historical & FOT crash/incident data and onboard driving data. Supplemental data sources are surveys & interviews and fleet operations records. Specific questions to be answered include:

1A.3-1 What characteristics (e.g., age, experience, driving record) of the specialty vehicle drivers are typical of other specialty vehicle drivers across the country?

1A.3-2 What characteristics (e.g., policies, mission, routes) of the specialty vehicles' operations are typical of other specialty vehicles' operations across the country?

1A.3-3 With what frequencies do IVI specialty vehicles encounter driving conflicts that are typical for comparable specialty vehicles across the country?

1A.3-4 What is the effectiveness of the IVI technologies for helping drivers avoid driving conflicts and reduce the probability of crashes that can be expected for drivers of comparable specialty vehicles across the country?

Objective 1A.4 Determine whether improved snow removal by snowplows equipped with IVI technologies impacts public safety.

Assuming that use of the IVI technologies leads to increased efficiency of snowplows, public safety may be affected. There may be fewer – or more – crashes of public vehicles as a result. Emergency vehicles (here, patrol cars and ambulances) may have increased response time due to improved route access because of the operation of a snowplow with IVI technologies. Furthermore, snowplows and emergency vehicles may have improved response time due to their self-contained IVI technologies. The public may choose to travel during periods of adverse conditions in which they would not ordinarily venture out, if they were aware that a snowplow (with the IVI technologies) has been able to remove snow from the roads.

While most of this plan's objectives are focused on the effects of the IVI technologies upon an individual specialty vehicle and its interactions with its environment, this objective explores the effects on public safety that may accrue from aspects of the specialty vehicles' performance with IVI technologies. Detailed analysis of subjective FOT data and summary analysis of literature review data will be required. The principal evaluation data sources related to this objective are operations records and special tests & supplemental data. Supplemental data sources are historical & FOT crash/incident data and surveys & interviews. Specific questions to be addressed include:

1A.4-1 Will there be more or fewer crashes of public vehicles due to improved snow removal?

1A.4-2 Will incident response times for emergency vehicles (patrol cars and ambulances, whether instrumented or not) be reduced because additional lane-miles have been cleared by snowplows with IVI technologies?

1A.4-3 Will incident response times for instrumented emergency vehicles be reduced because of their self-contained IVI technologies?

1A.4-4 Will the IVI technologies lead to more lives being saved due to improved response time by emergency vehicles?

1A.4-5 Will the IVI technologies result in emergency vehicles being significantly more visible to the general public?

1A.4-6 Does the improved ability to clear the roads encourage the public to drive when they should not be on the roads?

Goal 1B. Achieve an In-Depth Understanding of Mobility Benefits
Transportation mobility refers to the ease of movement, or perceived ease of movement as viewed by the traveling public. Benefits are usually measured in terms of travel-time savings, reduced congestion, and improvements in "customer" satisfaction. Reducing the number of crashes involving the target vehicles, an expected outcome of deploying the IVI technologies, will produce a mobility benefit. So may the increased road clearance that results from the IVI technologies. One of the most important mobility benefits could be reduced travel times, or the ability to keep roads open that otherwise would be closed, that would result from more effective snow removal enabled through this deployment. The number of crashes avoided with full deployment of the IVI technologies will be used along with information from the literature to estimate the value of the mobility benefit.

Objective 1B.1 Determine the value of the mobility benefit resulting from reduced snowplow, patrol car, and ambulance related crashes for inclusion in an overall benefit-cost analysis of the FOT.

The value of mobility benefits will be included in a benefit-cost analysis (see goal area 1D). Key measures will include literature-derived estimates of the impact of crashes on congestion, travel time, and traveler satisfaction. Summary analysis of literature review data will be required. The principal evaluation data sources related to this objective are historical & FOT crash/incident data and special tests & supplemental data. Specific questions to be addressed include:

1B.1-1 Will deployment of the IVI technologies result in a significant mobility benefit due to reductions in crashes involving snowplows, patrol cars, and ambulances?

1B.1-2 Will deployment of the IVI technologies result in a significant mobility benefit due to improved snow removal?

Objective 1B.2 Determine the value of the mobility benefit resulting from increased snow removal for inclusion in an overall benefit-cost analysis of the FOT.

The impact on public safety from improved snow removal (see objective 1A.4) will be included in a benefit-cost analysis (objective 1D.3). Detailed analysis of objective and subjective FOT data and summary analysis of literature review data will be required. The principal evaluation data sources related to this objective are operations records and special tests & supplemental data. A supplemental data source is surveys & interviews. The specific question to be addressed is:

1B.2-1 Will deployment of the IVI technologies result in a significant mobility benefit due to increased roadway snow clearance?

Goal 1C. Achieve an In-Depth Understanding of Efficiency Benefits
Efficiency generally refers to the amount of output (e.g., road miles plowed) for a given input (driver/vehicle days). The IVI technologies will affect the efficiency of specialty vehicle operations through reduction of the number of crashes or through operational impacts that can be measured in terms of productivity gains or losses (cost savings or increases). Thus, this goal area is combined with the goal area 1D – Productivity.

Goal 1D. Achieve an In-Depth Understanding of Productivity Benefits
Deployment of the IVI technologies can result in productivity increases through cost savings from reduced numbers of crashes and lower insurance rates. Other indirect productivity benefits such as time savings will be documented and valued. Of course there are cost increases associated with the purchase and maintenance of the systems, training costs for drivers and mechanics, and possibly operating costs.

Objective 1D.1 Determine the total costs to deploy and maintain the IVI technologies.

This objective focuses on conducting cost analyses on elements of the Mn/DOT IVI implementation technology life cycle for inclusion in the benefit-cost analysis. Detailed analysis of objective FOT data will be required. The principal evaluation data source related to this objective is operations records. A supplemental data source is surveys & interviews. The specific questions to be addressed are:

1D.1-1 What are the costs associated with developing the snowplow, patrol car and ambulance systems and their IVI infrastructure?

1D.1-2 What are the costs associated with the purchase of each vehicle system?

1D.1-3 What are the costs associated with maintenance of each vehicle system?

1D.1-4 What are the costs associated with the purchase of the infrastructure?

1D.1-5 What are the costs associated with operations and maintenance of the infrastructure, including training?

1D.1-6 What are the training costs for drivers and mechanics for each system?

1D.1-7 What are the operating costs for each system?

1D.1-8 What are the replacement capital purchase costs and depreciation rates?

1D.1-9 What are the costs of system upgrades?

Objective 1D.2 Estimate the cost savings (positive or negative) if use of the IVI technologies leads to an increase in the productivity and effectiveness of snowplow and emergency vehicle operations.

This objective addresses the cost savings that accrue when IVI technologies allow snowplow drivers to remove snow under circumstances when they could not without the IVI technologies or remove more snow from the roadway faster as a result of the technologies. The objective also includes the cost savings that accrue when emergency vehicles are able to respond to emergencies more quickly as a result of that improved snow removal.

Detailed analysis of objective FOT data will be required. The principal evaluation data source related to this objective is operations records. A supplemental data source is surveys & interviews. Specific questions to be addressed include:

1D.2-1 What are the cost savings when the IVI technologies allow the snowplow drivers to operate more hours per plow? To plow more miles per hour of operation? To reduce the time required clearing the roads?

1D.2-2 What are the cost savings from reduced infrastructure damage?

1D.2-3 What are the cost savings from lower driver turnover?

1D.2-4 What are the cost savings if incident response times for patrol cars and ambulances are reduced as a result of the IVI technologies?

Objective 1D.3 Conduct a comprehensive benefit-cost analysis to determine if the total benefits (from all sources) to society exceed the costs to develop and deploy.

A general framework for conducting a benefit-cost analysis of the Mn/DOT FOT will be prepared. However, the extent to which this comprehensive analysis will be pursued will depend on available resources. Detailed analysis of objective and subjective FOT data will be required. The principal evaluation data source related to this objective is special tests & supplemental data. Supplemental data sources are historical & FOT crash/incident data, onboard driving data, surveys & interviews, and operations records. The specific question to be addressed is:

1D.3-1 Is the total cost (to society) of developing, deploying, and maintaining the IVI technologies less than the combined value of all of the benefits?

Goal 1E. Achieve an In-Depth Understanding of Environmental Benefits
In addition to preventing injuries and fatalities, a reduction in the number of crashes resulting from the deployment of IVI technologies also benefits the environment in terms of reduced air pollution from traffic congestion caused by crashes.

Objective 1E.1 Determine the value of any environmental benefits that result from fewer snowplow, patrol car, and ambulance crashes, for inclusion in a benefit-cost analysis.

Environmental benefits or impacts may come from reductions in crash-related congestion. Summary analysis of literature review data will be required. The principal evaluation data sources related to this objective are historical & FOT crash/incident data and special tests & supplemental data. The specific question to be addressed is:

1E.1-1 Will deployment of IVI technologies result in fewer or more HAZMAT crashes?

1E.1-2 Will deployment of IVI technologies improve HAZMAT emergency response times due to use of IVSS or cleared roads?

1E.1-3 Will deployment of IVI technologies cause a decrease or increase in use of salt?

1E.1-4 Will deployment of IVI technologies cause any changes in air or noise pollution and fuel consumption?

The value of environmental impacts will also be considered in a benefit-cost analysis (see goal 1D).

Goal 2. Assess Impacts on Driver Acceptance
This goal area focuses on how IVI technologies affect the driving environment and the acceptability of the systems by the drivers. While Goal 1A (Safety Benefits) deals with the objective assessment of the impacts of IVI technologies on safe driving behavior, this goal focuses on understanding if and how human factors may play a role in the eventual acceptance and deployment of the systems.

Objective 2.1 Determine vehicle operator perceptions of the usability of the IVI technologies.

This objective focuses on how drivers perceive, understand, and respond to the functions, operations, and interfaces associated with the IVI systems. It involves how the drivers respond to specific characteristics of the IVI technologies and their understanding or "mental model" of them. Detailed analysis of subjective FOT data will be required. The principal evaluation data source related to this objective is surveys & interviews. A supplemental data source is onboard driving data. Specific questions to be addressed include:

2.1-1 Do operators perceive that the overall IVI system is useful and effective?

2.1-2 Under what conditions is the IVI system useful – e.g., snow, fog, darkness, rain?

2.1-3 Do operators perceive that the individual aspects of the IVI system are useful for:
- Navigation/lane-keeping?
- Collision avoidance?

2.1-4 Do operators perceive that the IVI system/technologies will increase safety?

2.1-5 How do operators use and interact with the IVI system/components; what elements of the IVI system do they use and why; what elements do they ignore?

2.1-6 What is the operator response to false alarms; is the level tolerable?

2.1-7 Do operators perceive the IVI system/components to be distracting or find it interferes with other tasks?

2.1-8 Do operators perceive that the placement of controls and displays associated with the IVI interface is appropriate for the:
- Heads-Up Display (HUD)?
- Auditory User's Interface (AUI)?
- Mirror Displays?
- Active Driver's Seat (HUI)?

2.1-9 Do operators perceive that the IVI displays and controls are visible/ audible/easy to feel/recognize?

2.1-10 Do operators perceive that the overall IVI system is easy to use?

2.1-11 Do operators perceive that the individual IVI components are easy to use:
- Heads-Up Display (HUD)?
- Auditory User's Interface (AUI)?
- Mirror Displays?
- Active Driver's Seat (HUI)?

2.1-12 How easy or difficult do operators perceive it was to learn to use the IVI system/ components:
- Heads-Up Display (HUD)?
- Auditory User's Interface (AUI)?
- Mirror Displays?
- Active Driver's Seat (HUI)?

2.1-13 Do operators perceive that they understand the IVI system capabilities?

2.1-14 Do operators perceive that they understand how to obtain and use the relevant IVI information?

Objective 2.2 Determine perceived effects of the IVI technologies on operator training requirements, job satisfaction, stress, workload, and fatigue.

This objective focuses on subjective reactions to the IVI technologies with respect to a number of indices of user contentment. Detailed analysis of subjective FOT data will be required. The principal evaluation data source related to this objective is surveys & interviews. A supplemental data source is onboard driving data. Specific questions to be addressed include:

2.2-1 What is the perceived impact of the IVI technologies on operator workload?

2.2-2 How does the perceived impact on workload affect fatigue; do other aspects of the IVI technologies independently impact fatigue?

2.2-3 What is the perceived impact of the IVI technologies on the level of operator stress on the job?

2.2-4 How are the IVI technologies perceived to affect overall job satisfaction?

2.2-5 What differential effects on workload, fatigue, stress, and job satisfaction, from the particular IVI system components, are perceived?

2.2-6 What perceived changes in operator training are necessitated by the addition of the IVI technologies?

2.2-7 Are the IVI technologies perceived to enhance driver situational awareness?

2.2-8 Are the IVI technologies perceived to increase the driver's ability to attend to the primary task of plowing?

2.2-9 Is the IVI system perceived to distract in any way from the primary task of plowing? If so, what features are distracting?

2.2-10 Are there any perceived installation issues (e.g., physical space) with regard to the IVI equipment that are problematic?

2.2-11 Is the IVI equipment perceived to present any physical hazards for drivers?

Objective 2.3 Determine perceived effects of the IVI technologies on the driver in terms of behavior risk modification and changes in driver vigilance.

While Objectives 1A.1 and 1A.2 addresses whether or not drivers modify their driving behavior (and the degree to which modified behavior is safe), this objective is concerned with learning whether drivers perceive that they modify their driving behavior as a result of the IVI technologies. Detailed analysis of objective and subjective FOT data will be required. The principal evaluation data source related to this objective is surveys & interviews. A supplemental data source is onboard driving data. Specific questions to be addressed include:

2.3-1 Do drivers perceive that they take more risks with the system than without it, perhaps because they have a greater awareness of potential safety hazards?

2.3-2 Do drivers perceive that they are more vigilant in their lane-keeping behavior with the system than without it, perhaps because of the feedback provided by the system?

2.3-3 Do drivers perceive that they become more dependent on the systems over time with the system than without it, especially in a manner that degrades their safety-related driving performance?

2.3-4 Do drivers perceive that they modify their driving behavior (speed, braking, lane keeping, turn signal usage) for particular reasons (to be determined) in response to the IVI systems?

Objective 2.4 Determine perceptions of product quality, value and maturity and establish customer willingness to pay.

This objective will obtain information on the perceived quality, value, and maturity of the IVI technologies from the perspective of the user (drivers, mechanics, and other support personnel). Issues related to willingness to pay will be addressed from the host organization's perspective. Opinions from other transportation managers will be solicited. Detailed analysis of subjective FOT data will be required. The principal evaluation data source related to this objective is surveys & interviews. Specific questions to be addressed include:

2.4-1 Do drivers and mechanics have recommendations for change that might improve the performance and functionality of the IVI technologies?

2.4-2 Do drivers and mechanics have recommendations for changes that might make it easier to use or learn how to use the IVI technologies?

2.4-3 Do the host agencies understand the potential benefits of the IVI technologies and, depending on cost, are willing to make more widespread deployment of these technologies?

2.4-4 What components or features of the IVI system particularly merit change and improvement?

2.4-5 What aspects of their job, if any, did they prefer prior to the IVI technologies? Why?

2.4-6 Are the levels of workload, fatigue, or stress associated with adding the IVI technologies problematic? If so, how can they be improved?

2.4-7 How can any difficulties related to learning to use the IVI technologies, or operator training, be improved?

2.4-8 If offered the chance not to use the IVI system, or specific components of it, would they choose not to? Why?

Goal 3. Assess System Performance
This goal area deals with the ability of the IVSS to perform their functions according to design specifications and meet minimum reliability and maintainability criteria. Performance, reliability, and maintainability are necessary, but not sufficient, conditions for achieving the expected benefits. Performance requirements could include those defined by the system developer(s) as well as those prepared by the evaluation team.

Objective 3.1 Characterize the expected performance and functionality of the IVI system.

The performance and functionality of each system will be characterized by analyzing the FOT test data with regard to repeatability, accuracy, system availability (down-time), calculated confidence levels in lane position estimates, and the effectiveness with which the information is communicated to and interpreted by the driver. Summary analysis of objective and subjective FOT data will be required. The principal evaluation data sources related to this objective are onboard driving data, and surveys & interviews. Supplemental data sources are operations records and special tests & supplemental data. Specific questions to be addressed include:

3.1-1 Are the performance characteristics of the system sufficient to provide accurate alarms to the driver regarding lane-keeping and potential hazards?

3.1-2 Are the systems functional for a sufficiently large portion of driving time to be effective?

3.1-3 Do the systems perform well under a variety of conditions and are not affected by weather, age of the equipment, or other factors?

3.1-4 How accurate is the IVI system overall?

3.1-5 How accurate are the individual components of the IVI system?
- Sensors: magnetic, radar, GPS
- Computers
- Interface: visual, audible, haptic

3.1-6 What components of the IVI system need refinement in terms of accuracy?

3.1-7 What are the drivers' perceptions regarding system accuracy?

3.1-8 Is the rate of false alarms problematic? If so, how can this rate be reduced?

Objective 3.2 Assess the capability of system components.

The capabilities of the components comprising the IVI system will be assessed by reviewing the design, test, and analysis activities performed by the FOT. Summary analysis of subjective FOT data will be required. The principal evaluation data source related to this objective is special tests & supplemental data. The results of this assessment will be critical to the analysis of the FOT data, because it will define the limitations of the system components (e.g., accuracy and repeatability). The specific question to be addressed is:

3.2-1 Are the capabilities of the IVI components adequate to meet the performance requirements of the IVI system?

Objective 3.3 Determine the expected reliability and maintainability of the IVI system.

The degree to which the IVI system is reliable and can be maintained over time is an important aspect of system performance. Summary analysis of objective and subjective FOT data will be required. The principal evaluation data sources related to this objective are onboard driving data, surveys & interviews, and operations records. The specific questions to be addressed include:

3.3-1 How reliable are the individual components of the IVI system?
- Sensors: magnetic, radar, GPS
- Computers
- Interface: visual, audible, haptic
- Packaging

3.3-2 How reliable is the IVI system overall?

3.3-3 What components of the IVI system need refinement in terms of reliability?

3.3-4 What types of repairs, down time, or system maintenance are associated with the FOT?

3.3-5 What are the drivers' and mechanics' perceptions regarding system reliability?

3.3-5 How maintainable will the IVI system be overall?

3.3-6 How maintainable will the individual IVI components be?
- Sensors: magnetic, radar, GPS
- Computers
- Interface: visual, audible, haptic
- Packaging

3.3-7 What problems exist with regard to maintenance of the IVI system; how can these be resolved?

Goal 4. Assess Product Maturity for Deployment
Although achieving benefits (Goals 1A-1D) and user acceptance (Goal 2) are necessary to achieve widespread deployment of intelligent vehicle systems, there are other factors that will determine success. In particular, it is important to consider the logistics and feasibility of large-scale production, production and installation costs, related infrastructure investments, and the need to achieve consistency with ITS standards and architecture.

Objective 4.1 Estimate production system purchase price, installation (after market), and maintenance costs.

The purchase, installation, and maintenance costs related to the IVI technologies as tested in this FOT are important to document. However, it is equally important to project these costs into the future when the systems are mass-produced and more fully deployed. Summary analysis of subjective FOT data will be required. The principal evaluation data source related to this objective is surveys & interviews. A supplemental data source is operations records. The specific question to be addressed is:

4.1-1 Are the costs of purchasing, installing, and maintaining the IVI technologies reasonable for specialty vehicle fleet owners?

Objective 4.2 Assess infrastructure investment needs.

Infrastructure investments related to the IVI technologies will be identified and costs estimated. Summary analysis of subjective FOT data and literature review data will be required. The principal evaluation data source related to this objective is surveys & interviews. Specific questions to be addressed include:

4.2-1 What is the infrastructure investment needed to install and maintain the magnetic tape?

4.2-2 What is the infrastructure investment needed to install and maintain the DGPS?

4.2-3 What is the infrastructure investment needed to map the geospatial database?

4.2-4 What is the infrastructure investment needed to install and maintain the weather sensors?

Objective 4.3 Check the availability of state-of-the-art, low cost manufacturing capabilities for the IVSS.

Special manufacturing capabilities might be needed to mass-produce IVI systems at competitive costs. Assessments of the manufacturing capabilities by the FOT participants, as well as those from independent experts in technology development are needed. Summary analysis of subjective FOT data and literature review data will be required. The principal evaluation data sources related to this objective are surveys & interviews and operations records. The specific question to be addressed is:

4.3-1 Are low-cost state-of-the-art capabilities available to mass-produce the IVI systems?

Objective 4.4 Evaluate and assess the need for modification to any necessary infrastructure for consistency with ITS standards and architecture.

The performance of the magnetic roadway tape, DGPS, and GIS mapping could be affected by surrounding infrastructure. Therefore, the dependency or influence of infrastructure deployment on the IVI technologies under test must be determined. Any infrastructure identified as influencing system performance should be analyzed to determine if standards and architecture properly control infrastructure configuration. Summary analysis of subjective FOT data will be required. The principal evaluation data source related to this objective is surveys & interviews. Specific questions to be addressed are:

4.4-1 Does system infrastructure influence the performance of the IVI?

4.4-2 Is any infrastructure that influences the IVI performance effectively controlled by ITS standards and infrastructure to allow IVI performance within design parameters?

Objective 4.5 Determine whether the IVI technologies are suitable for widespread deployment.

This objective is to determine whether the system is capable of being deployed in other operations. Summary analysis of subjective FOT data will be required. The principal evaluation data source related to this objective is surveys & interviews. The specific questions to be asked are:

4.5-1 Are the IVI technologies mature enough to be used in adverse conditions on other snowplows, patrol cars, and ambulances in other areas that are geographically similar to the FOT?

4.5-2 Are the IVI technologies capable of being used on other snowplows, patrol cars, and ambulances in adverse conditions in areas that are not geographically similar to the FOT?

Goal 5. Address Institutional and Legal Issues that Might Impact Deployment
Even though specialty vehicle drivers effectively meet the performance and benefit goals established, institutional and legal issues could influence the adoption of the technology. Improper performance of any IVI system could result in legal actions by drivers of the snowplows or other vehicles, or by the public. Likewise, institutional issues such as regions deciding not to deploy needed infrastructure could impair deployment.

Objective 5.1 Identify and determine the potential impact of institutional and legal issues.

Institutional and/or legal issues could influence the IVI system development, deployment and use. For example, institutional issues could emerge from the volume of information available on vehicle location. A specific legal action could result if a snowplow crashes into another vehicle under very poor conditions or under circumstances where the system clearly warned the driver of a potential hazard. Summary analysis of subjective FOT data and literature review data will be required. The principal evaluation data sources related to this objective are historical & FOT crash/incident data and surveys & interviews. A supplemental data source is operations records. Specific questions to be addressed include:

5.1-1 What legal or institutional issues can result from the deployment of the IVI technologies?

5.1-2 What mitigating actions can be taken to help reduce the impact of legal and institutional issues?

5.1-3 Can liabilities be controlled to limit impediments for implementation and use?

3.3 Evaluation Accomplishments and Factors Affecting the Achievement of Evaluation Goals and Objectives

Although some evaluation objectives were met, the lack of low visibility weather events during the winter of 2001-2002 made it impossible to achieve most of the evaluation goals and objectives that were established for this FOT. Although the drivers operated vehicles with active systems, there were too few opportunities to test the systems under the low visibility conditions for which they were designed to be used. Other factors, such as deployment delays, limitations on the experimental design, and the level of maturity of the driver-vehicle interfaces, also had impacts on the achievement of certain goals. Below we review what was accomplished and discuss pertinent factors that affected our ability to achieve the evaluation objectives.

Goal 1A. Achieve an In-Depth Understanding of Safety Benefits

Objective 1A.1 Determine whether drivers drive more safely with the IVI technologies than without them.

Objective 1A.2 Determine whether vehicles with IVI technologies will have fewer crashes than vehicles without the system.

Although more than 300 hours and 11,000 miles of driving data were collected during the FOT, less than 25 percent of the data were collected while the driver-vehicle interface was turned on (i.e., the driver had the opportunity to receive messages and warnings). The data are described in Section 5.1 and some preliminary classifications of potential driving conflicts are presented in Section 6.1. However, no inferences can be made concerning the effectiveness of systems for improving driving safety and avoidance of crashes because (a) virtually no data were collected under low visibility conditions, (b) the amount of data collected with the system activated (less than 75 hours total) is inadequate, and (c) critical features of the experimental design (related to activation of the systems) were not carried out. In particular, it was not possible to compare driving behaviors under low visibility conditions both with and without the use of the IVSS.

Objective 1A.3 Determine the numbers of crashes, injuries, and fatalities that could be avoided if all snowplows, patrol cars, and ambulances in the United States that operate in areas of reduced visibility were equipped with IVI technologies.

This objective could not be met without completing Objective1A.2. However, a survey of states was initiated and a literature search was conducted to obtain various types of information that would be needed to extrapolate findings from this FOT. Specifically, we gathered information on numbers of snowplows, lane-miles of roads, population, and land area by state; and average snowfall by weather station. We also obtained detailed weather information and data on snowplow crashes within the state of Minnesota. This information is summarized in Section 5.4.

We did not attempt to identify corresponding information on ambulance and patrol car crashes nationwide because it was not feasible to extrapolate the findings from this limited test involving only one vehicle of each type.

Objective 1A.4 Determine whether improved snow removal by snowplows equipped with IVI technologies impacts public safety.

The plan was to use operational data and driver interviews to estimate how much more quickly the snowplows cleared the roads and emergency vehicles responded to incidents when the IVSS technologies were used during low visibility conditions. However, without such conditions it was not possible to obtain information with which to assess these impacts. We did obtain historical crash data on Trunk Highway 7 for a seven year period in order to determine the frequency of crashes that occurred during snowy conditions. This information is summarized in Section 5.4.

Goal 1B. Achieve an In-Depth Understanding of Mobility Benefits

Objective 1B.1 Determine the value of the mobility benefit resulting from reduced snowplow, patrol car, and ambulance related crashes for inclusion in an overall benefit-cost analysis of the FOT.

Objective 1B.2 Determine the value of the mobility benefit resulting from increased snow removal for inclusion in an overall benefit-cost analysis of the FOT.

This FOT did not produce information on the mobility benefits of the IVSS technologies for specialty vehicles. However, the discussion of the technical approach to the benefit-cost analysis, presented in Section 6.9, identifies potential sources of information from organizations and the literature that might be used to quantify the value of mobility benefits.

Goals 1C and 1D. Achieve an In-Depth Understanding of Efficiency and Productivity Benefits

Objective 1D.1 Determine the total costs to deploy and maintain the IVI technologies.

Information on costs to deploy and maintain the systems was obtained by the Mn/DOT partners (Evaluation Report Volume 2: Benefit Analysis, Intelligent Vehicle Initiative Specialty Vehicle Field Operational Test December 2002). Our approach to obtaining costs is presented in Section 6.9 as part of the benefit-cost analysis.

Objective 1D.2 Estimate the cost savings (positive or negative) if use of the IVI technologies leads to an increase in the productivity and effectiveness of snowplow and emergency vehicle operations.

This objective was not met because the FOT did not yield information on cost savings or impacts on productivity and effectiveness of operations.

Objective 1D.3 Conduct a comprehensive benefit-cost analysis to determine if the total benefits (from all sources) to society exceed the costs to develop and deploy.

A more detailed approach to the benefit-cost analysis was developed and sources of data from historical databases and the literature were sought. The approach to the benefit-cost analysis is presented in Section 6.9.

Goal 1E. Achieve an In-Depth Understanding of Environmental Benefits

Objective 1E.1 Determine the value of any environmental benefits that result from fewer snowplow, patrol car, and ambulance crashes, for inclusion in a benefit-cost analysis.

Because we were lacking information on crash reductions we did not attempt to quantify environmental benefits.

Goal 2. Assess Impacts on Driver Acceptance

Objective 2.1 Determine vehicle operator perceptions of the usability of the IVI technologies.

Objective 2.2 Determine perceived effects of the IVI technologies on operator training requirements, job satisfaction, stress, workload, and fatigue.

Objective 2.3 Determine perceived effects of the IVI technologies on the driver in terms of behavior risk modification and changes in driver vigilance.

Objective 2.4 Determine perceptions of product quality, value and maturity and establish customer willingness to pay.

All of these objectives were met to the extent that drivers were able to form meaningful opinions under the conditions experienced in the FOT. However, the drivers had limited experience using the systems under low visibility conditions. Also, deployment delays and system performance issues may have influenced driver perceptions. A separate report (Mn/DOT Driver Acceptance: IVI FOT Evaluation Report, Battelle White Paper, June 30, 2003) on the results of the driver acceptance study was delivered to USDOT.

Goal 3. Assess System Performance

Objective 3.1 Characterize the expected performance and functionality of the IVI system.

Objective 3.2 Assess the capability of system components.

The Mn/DOT partners conducted system validation tests (ref *Draft Validation Report, Intelligent Vehicle Initiative Specialty Vehicle Field Operational Test,* March 2002). Battelle did not have the opportunity to participate in the design or conduct of these tests and did not analyze the data. However, Battelle did prepare formal recommendations for system performance tests. These tests are described in Appendix F.

Objective 3.3 Determine the expected reliability and maintainability of the IVI system.

This objective was not met. Data on maintenance and reliability of the IVI systems were maintained by the Mn/DOT partners (see Appendix A: Design & Changes/Maintenance/ Complaint Log). However, the system usage time due to the mild weather was insufficient for making this determination.

Goal 4. Assess Product Maturity for Deployment

Objective 4.1 Estimate production system purchase price, installation (after market), and maintenance costs.

Objective 4.2 Assess infrastructure investment needs.

Objective 4.3 Check the availability of state-of-the-art, low cost manufacturing capabilities for the IVSS.

Objective 4.4 Evaluate and assess the need for modification to any necessary infrastructure for consistency with ITS standards and architecture.

Objective 4.5 Determine whether the IVI technologies are suitable for widespread deployment.

These objectives were not met due to the limited findings derived from the FOT.

Goal 5. Address Institutional and Legal Issues that Might Impact Deployment

Objective 5.1 Identify and determine the potential impact of institutional and legal issues.

This objective was partially met through interviews with the drivers. Findings are presented in Battelle's White Paper (ref *Mn/DOT Driver Acceptance: IVI FOT Evaluation Report,* June 30, 2003). External sources of information on institutional and legal issues were not pursued.

4.0 EVALUATION APPROACH

This chapter presents a high-level summary of our technical approach; focusing on what data are needed and how the data are used to achieve the evaluation objectives. Table 4-1 illustrates how five different types of data play principal (P) or supporting (S) roles in achieving each of the evaluation objectives. A brief discussion of each data source is presented below. However, detailed descriptions of each type of data and how they should be collected, and the analysis approaches for achieving the evaluation objectives are presented in Sections 5 (Evaluation Data) and 6 (Analysis Methods), respectively.

Onboard Driving Data

The six test vehicles were equipped with on-board data acquisition systems for monitoring vehicle kinetics, selected channels from IVSS (e.g., radar image range, range rate, and azimuth), special sensors, and video images (four cameras). The primary use of the data for Battelle's evaluation purposes was to measure the degree to which drivers drive more safely with IVSS (Objective 1A.1) and estimate reductions in driving conflicts and crashes (Objective 1A.2). These data also play a principal role in evaluating system performance and reliability (Goal Area 3) by monitoring GPS signal quality, false alarm rates, and other performance measures. (It should be noted that during the FOT, the vehDAQ was not configured to provide information about alarms from any of the six test vehicles. The only way to detect the incidence of alarms would have been through examining the video data gathered by an in-cab camera). Driving data also support the driver acceptance analysis (Goal Area 2) by tracking system utilization (amount of time system is turned on and alarm volume turned up) and frequencies of alarm activation and risky behaviors.

Literature, Historical and Reference Data

Several types of reference data are needed to extrapolate the benefits and costs estimated from this FOT. Historical crash data on snowplows and emergency vehicles are needed to determine the types of driving conflicts that might lead to certain types of crashes (Objective 1A.2) and to establish the number of crashes that might be avoided at full deployment (Objective 1A.3). For this study Mn/DOT provided over 300 crash reports involving snowplows from four districts between 1995 and 2000. For the benefit-cost analysis we conducted a preliminary telephone survey of states to determine number of snowplows that might be equipped with IVSS at full deployment nationwide. Various reference sources were used to obtain data on the potential exposures to low visibility driving conditions – specifically, the number of lane-miles of roads in the state and average snowfalls. Mn/DOT provided relevant information on over 1,500 individual crashes that occurred on TH-7 between 1995 and 2001. Weather data from 205 Minnesota weather stations during the period 1993-2001 were also made available.

Surveys and Interviews

Survey and interview data play a principal or supporting role in achieving nearly all of the evaluation goals. Interviews with operations managers, maintenance personnel, and external experts are needed to assess productivity and efficiency benefits, determine costs, support the evaluation of system performance, and assess institutional and legal issues. Surveys and interviews are also the principal means of obtaining information from the drivers concerning their acceptance of the IVSS, perceptions of system quality, and recommendations for improvements. In particular, the following data collection activities were undertaken during the FOT:

- In-person interviews conducted in December 2001;
- Internet survey conducted in January 2002;
- Internet survey conducted in April 2002; and
- In-person interviews conducted in April 2002.

The first driver interviews and survey were focused on driver expectations. The second survey and interviews were focused on driver experience, particularly during low-visibility driving conditions. Results from the driver surveys and were published separately in the Battelle White Paper – *Mn/DOT Driver Acceptance: IVI FOT Evaluation Report,* June 30, 2003.

Fleet Operations Records

Various types of operational data are needed for this evaluation. The safety benefits analysis and the assessment of productivity and efficiency benefits require that driving data be matched to driver assignments, activity logs, traffic, road and weather conditions, maintenance activities, and driving incidents and accident reports. The *Mn/DOT IVI FOT Design & Changes/ Maintenance/Complaint Log* (see Appendix A) contains the operator's maintenance and operation records that were relevant to the FOT. This document was originally intended to help estimate the costs or savings associated with the IVSS, but the limited data resulting from light usage during the mild winter conditions were insufficient to make such a determination.

Special Tests and Supplemental Data

This category includes all sources of data outside the FOT itself. The only significant special test performed was Mn/DOT's system validation tests, which support the system performance analysis. These tests were performed shortly before the FOT began. Also, literature sources are needed to estimate the public safety benefits of improved snowplowing efficiency using IVSS and to quantify the mobility and environmental impacts of improved snowplowing efficiency.

Table 4-1. Principal (P) and Supplemental (S) Data Sources for Addressing Evaluation Goals and Objectives

Evaluation Data Sources → / Goal Area/ Objectives	Onboard Driving Data	Literature, Historical and Reference Data	Surveys and Interviews	Fleet Operations Records	Special Tests and Supplemental Data	Comments
Assess Safety Benefits						Historical data are needed to identify relevant crash types, conflicts, and driving behaviors. Crash avoidance models are based on driving data. Surveys will add driver perspectives concerning stress, nuisances, etc. Driver records and vehicle safety records are needed for extrapolation of results. Literature results will be used to estimate the public safety impact of improved snow removal.
1A.1 Determine if drivers drive more safely	P	S	S	S		
1A.2 Estimate crash reductions	P	P				
1A.3 Estimate crash reductions at full deployment	P	P	S	S		
1A.4 Determine if improved snow removal impacts public safety		S	S	P	P	
(more/fewer crashes and increased emergency vehicle response times)						
Assess Mobility Benefits						Literature findings and historical crashes will be used to estimate the impact of crash reductions (from 1A.3) on mobility. Literature findings will be used for mobility impact of improved snow removal.
1B.1 Assess impact of reduced crashes on mobility		P			P	
1B.2 Assess impact of improved snow removal on mobility			S	P	P	
Assess Efficiency/Productivity Benefits						Interviews, site visits, and vehicle records are the primary sources of deployment and maintenance cost data. The benefit-cost analysis combines literature results with FOT findings on specific costs and benefits to estimate total costs and benefits to society.
1D.1 Determine cost to deploy and maintain IVSS			S	P		
1D.2 Estimate cost savings (pos or neg) with IVSS			S	P		
1D.3 Conduct comprehensive benefit-cost analysis	S	S	S	S	P	
Assess Environmental Benefits						Literature findings and historical crashes will be used to estimate the impact of crash reductions (from 1A.3) on the environment (from reduced congestion and HAZMAT spills).
1E.1 Assess impact of reduced crashes on environment		P			P	
Assess Driver Acceptance						Driving data will be used to establish utilization and availability, determine alarm frequencies, and objectively characterize driving risks and behaviors. Surveys and interviews will address driver perceptions of all aspects of IVI technologies.
2.1 Determine perceptions of usability (understanding, training…) of IVSS	S		P			
2.2 Determine if drivers perceive increased driving stress and workload	S		P			
2.3 Determine perceived impacts on driver risks and vigilance	S		P			
2.4 Determine perceptions of product quality, maturity, etc.			P			

Evaluation Data Sources → Goal Area/ Objectives	Onboard Driving Data	Literature, Historical and Reference Data	Surveys and Interviews	Fleet Operations Records	Special Tests and Supplemental Data	Comments
Assess IVSS Performance and Capability Potential 3.1 Characterize performance/functionality of components 3.2 Assess capability of components 3.3 Determine reliability and maintainability of components	P P		P P	S P	S P	Component performance, functionality, reliability, and maintainability will be addressed with objective driving and maintenance data as well as interviews with drivers and mechanics. Capability is addressed through special engineering tests and measurements.
Assess Product Maturity for Deployment 4.1 Determine if costs are reasonable for motor carriers 4.2 Assess infrastructure investment needs 4.3 Determine availability of manufacturing capabilities 4.4 Assess need for modifications to ITS standards 4.5 Determine if IVI technologies are suitable for widespread deployment			P P P P P	S	P S	In addition to the planned surveys and interviews of drivers, mechanics, and operations managers, special "key informant interviews" will be conducted with experts on technology deployment, manufacturing, etc. Agencies such as state DOTs, ITS America and weather-related consortia will be surveyed as needed.
Assess Impact of Institutional/Legal Issues 5.1 Identify and determine impact of institutional/legal issues		P	P	S		In addition to the planned surveys and interviews of drivers, mechanics, and fleet managers, special "key informant interviews" will be conducted with experts in insurance and product liability. Agencies such as state DOTs will be surveyed as needed.

5.0 EVALUATION DATA

There were a number of different types of data that were needed for the evaluation approach. These included the onboard driving data; surveys and interviews; operations data; literature, historical and reference data; and validation test data. The following sections describe the different types of data that were collected during the FOT.

5.1 FOT Driving Data

The following sections describe the on-board driving data that were collected, summarize the steps used to process and assess the quality of the data, and characterize the volume of data that were available for analysis.

5.1.1 Description of Data

The FOT generated multiple sources of data for assessing the safety benefits of the IVSS. These data include a digital map of the test region, engineering information collected from the test vehicles, video data recorded on the test vehicle, and information regarding the visibility at several points along the test corridor.

Digital map

Mn/DOT provided Battelle with an ArcView® database containing a digital representation of the test corridor roadways, shown in Figure 5-1. This digital map detailed the lane centers, lane boundaries, road shoulders, and some roadway furniture (i.e., mailboxes, jersey barriers) along the test corridor. These data were then converted into a SAS dataset, which consisted of a series of points defining the line segments that make up the map.

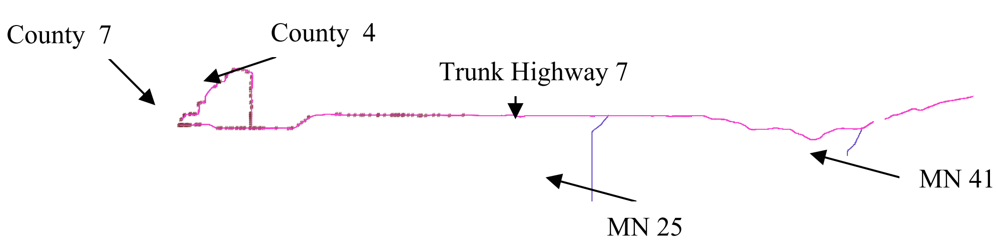


Figure 5-1. Digital Map of the Test Corridor

On-Board Data Elements

When a specialty vehicle was in operation on TH-7 or any of the control road sections, its vehicle data acquisition system (vehDAQ) collected data continuously at 10 hertz from the various safety systems. More limited data pertaining to lane-keeping only were collected when a vehicle was on a control road. The data recorded from the test vehicles contained information to identify the truck, the driver, the time and the date. The engineering data also contained variables depicting the position and performance of the test vehicle. These variables included the GPS coordinates, accelerations in three spatial directions, speed and heading of the vehicle, the steering wheel position, and brake pedal status. There were also x and y GPS coordinates for any targets detected by the IVSS, as well as the rate of change of those coordinates.

- GPS Date (MM-DD-YY)
- GPS Time (HHMMSS.S)
- GPS X (meters)
- GPS Y (meters)
- GPS Z (meters)
- GPS Quality Index (0=no solution, 1=uncorrected, 2=differential, 4=fix, 5=float)
- GPS Num of Satellites
- GPS HDoP (less than 3 good)
- Vehicle Speed (mph)
- Vehicle Heading (radians)
- IMU ROT X Rate (rad/s)
- IMU ROT Y Rate (rad/s)
- IMU ROT Z Rate (rad/s)
- IMU Acceleration X (m/s)
- IMU Acceleration Y (m/s)
- IMU Acceleration Z (m/s)
- Control Panel Master On-Off
- Steering Position
- Brake Position
- Turn Signal Status
- Driver Specified Lateral Offset
- Vehicle Lateral Offset
- 3M Sensor Status – Left
- 3M Sensor Distance – Left*
- 3M Sensor Status – Right
- 3M Sensor Distance – Right*
- Audio volume
- Altra Sensor Status* (1=working, 0=not working)
- Altra Prog_Status_Left* (1=working, 0=not working)
- Altra_Prog_Status_Right* (1=working, 0=not working)
- Altra_Prog_Sensor_Alarm_Left* (0=nothing, 1=close alarm, 2=far alarm)
- Altra_Prog_Sensor_Alarm_Right* (0=nothing, 1=close alarm, 2=far alarm)
- Number of Targets

For each target detected by the radar unit on the specialty vehicle, the following information was recorded (Battelle stores in separate table)

- Target X (meters)
- Target Y (meters)
- Target X_DOT
- Target Y_DOT

Data Quality Measures

The on-board data also contained various quality measures for the data, and specifically the performance of the GPS positioning. One such variable was the measure of the horizontal dilution of precision (HDOP). This variable is a measure of the error associated with the GPS position reading, and a value less than three is considered acceptable. Another measure of the quality of the data was the GPS quality index. This variable speaks to the accuracy of the GPS coordinates. A quality index value of 4 indicates a reading that is accurate to within 4 cm. If the quality index variable has a value of 5 the reading is accurate to within 20 cm. The remaining index values indicate readings that are not accurate to within 20 cm and could not be used in this project. A final quality measure is the number of satellites used to calculate the position of the test vehicle. Any reading that was derived from three or more satellites was considered to be a valid reading.

Video

Files containing video images were available to Battelle when requested. Each clip contained four images simultaneously showing the view out of the test vehicle cab, the driver, the driver's feet, and the driver's hands. The video also included some of the engineering data elements overlaid on the image. They included the three GPS position variables, the steering wheel position, and the brake pedal position. Some video clips were requested to examine potential anomalies in the data. For example, one test vehicle was registering targets traveling at over two hundred miles per hour. The video data showed no targets during these time periods, suggesting that these were erroneous targets.

Visibility

Mn/DOT provided Battelle with the visibility data recorded from six weather stations located along TH 7. The data contained variables pertaining to the average visibility for the previous one-minute and the previous ten-minutes. There was also a measure of the current precipitation, the water intensity, NWS and WMO codes to identify the weather conditions, and an indicator to determine when the low visibility alarm was triggered. The dates and times of each reading were recorded, as well as the GPS coordinates of each station.

5.1.2 Data Processing

Visibility vs. Time and Location

The visibility data were matched to the engineering data based on the location of the vehicle, the date and the time. The GPS time from the engineering data was converted to Central Standard Time to match the visibility data. The visibility data for the two closest stations was merged to the engineering data by date and time (rounded to the closest 5 minutes). If the specialty vehicle was at either end of the test route (beyond the furthest weather station) the data for that one weather station was the only data used for visibility. Otherwise the visibility for the vehicle was calculated as a weighted average of the two visibility readings from the two closest weather stations. The average was weighted by the inverse of the distance to the station (i.e., the closer station was given more weight).

Data Quality Measures

Some of the variables listed above were used to determine the quality of the individual GPS readings as discussed above. Data values were removed for the following reasons: HDOP measurements of greater than three, GPS Quality Index that was less than 4, and any time the number of satellites reporting was less than 3. The engineering data were also checked for repeated time coordinates suggesting a drop-out of GPS signal. The results of this filtering can be seen in the tables below. Table 5-1 shows the distribution of the HDOP variable seen in the engineering data. More than ninety nine percent of the data are less than 3, meaning that the GPS reading information had a low enough error rate to be used in the analysis.

Table 5-1. Distribution of Horizontal Dilution of Precision (HDOP) by Vehicle Type

	Ambulance			Patrol Car			Snowplows		
HDOP	**VMT**	**Time**	**% Time**	**VMT**	**Time**	**% Time**	**VMT**	**Time**	**% Time**
<3	2481	46.0	98.8%	982	26.8	99.7%	7899	243.0	99.7%
>= 3	30	0.6	1.2%	2	0.1	0.3%	28	0.8	0.3%

Table 5-2 shows a distribution of the GPS quality index seen in the engineering data. Over ninety percent of the data have a GPS quality index of 4 or 5, meaning that the GPS readings for these data have enough accuracy to be used in the analysis.

Table 5-2. Distribution of GPS Quality Index by Vehicle Type

	Ambulance			Patrol Car			Snowplows		
GPS_QUAL_INDEX	**VMT**	**Time**	**% Time**	**VMT**	**Time**	**% Time**	**VMT**	**Time**	**% Time**
0	31	0.6	1.2%	10	0.2	0.9%	60	1.7	0.7%
1	11	0.2	0.5%	14	0.3	1.0%	108	3.4	1.4%
2	150	2.9	6.2%	39	0.8	3.0%	399	11.9	4.9%
4	1131	21.3	45.8%	579	16.9	63.1%	4557	143.2	58.7%
5	1187	21.6	46.3%	342	8.6	32.0%	2803	83.7	34.3%

Table 5-3 shows the distribution of the number of satellites in the engineering data. Over ninety five percent of the data were recorded with positioning information from at least three satellites, meaning that the position of the vehicle could be accurately determined.

Table 5-3. Distribution of Number of Satellites by Vehicle Type

	Ambulance			Patrol Car			Snowplows		
Number Satelites	**VMT**	**Time**	**% Time**	**VMT**	**Time**	**% Time**	**VMT**	**Time**	**% Time**
0	31	0.6	1.2%	9	0.2	0.8%	57	1.6	0.7%
1			0.0%			0.0%	0	0.0	0.0%
3	4	0.1	0.2%	1	0.1	0.2%	7	0.2	0.1%
4	36	0.7	1.6%	4	0.1	0.6%	104	3.3	1.3%
5	213	4.1	8.8%	109	2.8	10.3%	751	21.9	9.0%
6	646	12.2	26.2%	335	8.4	31.4%	2298	68.9	28.2%
7	988	18.2	39.1%	347	10.2	37.9%	2929	91.5	37.5%
8	417	7.6	16.3%	166	4.8	17.8%	1347	43.4	17.8%
9	177	3.1	6.7%	12	0.3	1.1%	433	13.1	5.4%

Figure 5-2 below indicates areas with consistently low quality data. In particular, the area along Trunk Highway 7 between Mn. 41 and Mn. 25 is an area of poor GPS coverage. More than fifty percent of the data recorded along this route were routinely eliminated from the analysis. The problems with GPS coverage in this region was known ahead of time. This area appears to be the only area consistently lacking GPS coverage.

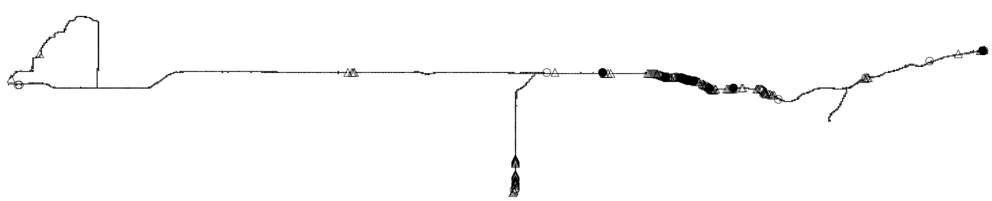


Figure 5-2. Map of Observed Data Quality on Test Corridor

Filtering of Continuous Data

The GPS coordinates, vehicle speed, and vehicle heading variables were checked for spikes (and dips) within a given time segment. In the engineering data, occasionally values were observed that represented physical impossibilities: speeds greater than two thousand miles per hour, or vehicles turning completely around in a tenth of a second. In order to deal with these data the 99th percentile of the difference of each variable from one time point to the next was calculated. The previous five values (within a continuous time segment) of the variable were used in a simple linear regression against time to predict the next value. If the current value was different from the predicted value by more than the 99th percentile of differences, that point was replaced by the predicted value and the process was repeated for each point in the dataset.

5.1.3 Volume of Data Available for Analysis

The following are summaries of the data collected and used, by visibility and vehicle type. Table 5-4 shows the total data collected by vehicle type, road type, and visibility. The majority of data recorded during this FOT occurred during periods of reasonably high visibility. What little data were recorded during periods of low visibility occurred during periods when the IVSS was manually turned off.

Table 5-4. Total Data Collected by Vehicle Type, Road Type, System Status and Visibility

Vehicle	Control Road	Control Master	Visibility 100 - 200 meters		Visibility 200 - 300 meters		Visibility > 300 meters	
			# Hours	VMT	# Hours	VMT	# Hours	VMT
Ambulance	Control	Off					0.2	13
		On					0.1	4
	Test	Off					37.2	2,004
		On					8.6	471
Patrol Car	Control	Off					0.3	4
		On					0.0	1
	Test	Off	0.0	1	0.0	0	21.8	769
		On					4.6	205
Snow Plow	Control	Off					17.7	529
		On					6.2	176
	Test	Off	0.0	1	0.2	4	165.0	5,233
		On			0.1	0	53.8	1,969

VMT = vehicle miles traveled.
“Control” refers to control roads as defined in Section 2.2.2
“Test” refers to the Trunk Highway 7 or McLeod County Road 7 sections in the field test
“Control Master” refers to whether the IVSS was turned on or off.

Table 5-5 shows a summary of the data remaining after the quality checks were performed and low quality data were removed. The low quality data appears to be evenly spread across vehicle types and visibility. Table 5-5 illustrates that only very limited data were available for analysis and even less of that collected when the system was turned on and visibility was limited.

Table 5-5. Total Data Remaining after Data Quality Filters by Vehicle Type, Road Type, System Status and Visibility

Vehicle	Control Road	Control Master	Visibility 100 - 200 meters		Visibility 200 - 300 meters		Visibility > 300 meters	
			# Hours	VMT	# Hours	VMT	# Hours	VMT
Ambulance	Control	Off					0.2	13
		On					0.1	3
	Test	Off					33.5	1,804
		On					7.3	401
Patrol Car	Control	Off					0.3	4
		On					0.0	1
	Test	Off	0.0	1	0.0	0	19.5	670
		On					4.1	180
Snow Plow	Control	Off					16.0	476
		On					5.6	157
	Test	Off	0.0	1	0.2	3	149.1	4,707
		On			0.1	0	48.5	1,770

NOTE: Mobility Benefits (Goal 1B), Efficiency/Productivity Benefits (Goals 1C and 1D) and Environmental Benefits (Goal 1E) are not presented because the FOT did not generate useful data on snowplow usage, road closures, snowplowing efficiency/productivity, environmental impacts, or crash reduction.

5.2 Surveys and Interviews

This section describes the data needed to assess driver attitudes, perceptions, and self-reported behaviors and experiences with the IVI technologies. Information from other key informants, such as managers, mechanics, dispatchers, and other experts is also important. The Mn/DOT FOT addressed the specialized case of the use of IVI technology to improve the operations of specialty vehicles, including snowplows, ambulances, and state patrol cars. In large part due to this specialized nature, the sample of vehicles outfitted with the technologies, and thus the number of drivers involved in the FOT, was relatively small. However, due to the level of cooperation from the Mn/DOT Partners, access to drivers was extremely good, allowing us to explore the relevant issues in greater depth as well as to have a higher than usual rate of response from drivers. Thus, the character of this driver assessment was predominantly qualitative in nature.

The driver interaction tools were designed to be used to help assess a number of driver acceptance issues, in particular addressing:

1) Operators' use of the system and changes from past practices.
2) Ease-of-use of the system and its components.
3) Operators' perceptions of system impact on stress, fatigue, job satisfaction, task performance, and workload.
4) Changes needed in the area of operator training.
5) Aspects of the IVI system needing improvement and means for improvement

6) Operators' views regarding system effectiveness and utility.
7) Perceived impact on safety.
8) Operators' response to false alarms and other potentially distracting elements
9) Operators' perceptions of effects on critical driver behaviors
10) Use of the system and components; ratings of individual features.

Table 5-6 summarizes the scope of diver interaction tools that was intended in this FOT evaluation.

Table 5-6. Summary of Interviews and Surveys

Group of Key Informants	Data Collection Method	Subjects (#)	Topics Covered	Objectives
IVI Drivers	» Surveys (telephone interviews with each driver)	34	Driver perceptions, expectations, experiences, and acceptance	2.1 – 2.4
	» In-person interviews / Focus Groups	~ 12		3.1, 3.3
	» Call-in for unusual driving event interviews (as events occur)			
Technicians / Mechanics	Interviews	4-8	System performance, acceptance, maintenance, and reliability	1A.2 3.1, 3.3
Supervisors	Interviews	4	System performance, use, and value	1A.4, 1D.1 - 1D.2, 2.1, 2.2, 2.3, 3.1, 3.3 4.1 – 4.5
Dispatchers	Interviews	TBD	Benefits related to vehicle dispatch and recall decisions related to severe weather	1A.4, 1D.2
Manufacturing experts / operating organizations	Interviews	TBD	Product maturity, product potential, suitability for widespread deployment	1A.3 4.1 – 4.5
Legal department / Insurance companies	Interviews	4-6	Institutional and legal issues	5.1
Emergency management agencies	Interviews	TBD	Perspective on value and impacts of IVI technologies	1.A-4, 1B-1-1B.2

All those who participated in surveys and interviews were explicitly informed that their specific responses would be kept confidential and results would be presented only in an aggregated form. As a general matter, all drivers signed an informed consent clause that gave them the right to not answer some or all of the questions (see Appendix B). Confidentiality of all responses by drivers in the interview process was assured, and no driver names were released or connected with any of their responses. The Battelle evaluation team cleared all questions and survey forms through the human subjects Internal Review Board to assure fair and equitable treatment of respondents.

Data collection included two in-person interviews with drivers and their supervisors and two Internet-based surveys of the drivers. These were used to gather baseline information before the drivers had significant experience with the new IVSS technologies and later after they had experience with the technologies under the winter conditions for which they were designed. Details of the two interviews and the two Internet surveys are contained in the Battelle White Paper – *Mn/DOT Driver Acceptance: IVI FOT Evaluation Report,* June 30, 2003[2]. The questions used to guide interviewees and the Internet survey screens as the respondents saw them, are included as Appendices B – E respectively.

An objective of the initial baseline Internet survey (18 drivers) was to assess driver expectations for the use of the safety technologies and to ask drivers about their experiences with early versions of the technologies. It was known at the outset that there had been significant technical problems with the performance of the GPS in particular that resulted in incorrect or unusable displays of roadway information that could not be corrected prior to the start of the FOT. The final Internet survey (13 drivers) sought to identify changes in driver perceptions based on their experiences with the IVSS. The baseline driver interviews (12 drivers) and final interviews (12 drivers) supplement the objective data collected in the surveys with a more open-ended, subjective discussion of expectations, experiences, and issues with the technologies. In addition to the data collected from the drivers, baseline and final interviews were conducted with selected supervisors (4 in the first interview and 3 in the second interview) in order to obtain their perspective on these safety systems.

As we learned from the driver and supervisor in-person interviews conducted in December 2001, early problems with the technologies appeared to cause some drivers to have reduced expectations regarding the potential to experience benefits from these systems at the outset of the evaluation. The final Internet survey and interviews sought to evaluate whether and how driver attitudes, perceptions, and behaviors with regard to each of the IVSS technologies changed as the drivers gained experience using the technologies and to the extent that the bugs were worked out.

Three other factors are known to have had an impact on driver responses and observations obtained from the surveys and interviews:

1. Drivers who participated in the surveys and interviews were operating very different vehicles under different conditions, associated both with the vehicle type and with the geographic areas in which they operate. For example, snowplows operating in more rural environments encountered very different driving conditions from snowplows operating closer to the city, in

[2] Information that could reveal a driver's identity has been removed from this report, as all drivers were assured of confidentiality in the surveys and interviews.

"urban corridors," and snowplows operated differently and under different conditions from ambulances or state patrol cars. Notwithstanding these differences, however, there was substantial agreement among the drivers on many of the topics covered in this evaluation. Where significant differences occurred in driver responses, these were discussed separately.

2. As was true for the entire IVI evaluation, the generally mild weather conditions that occurred between the baseline data collection and the final data collection approximately three months later significantly limited driver opportunity to experience the use and benefits of these safety systems. The evaluation timeframe provided at most two short instances of the kind of low visibility driving conditions that were considered essential to test the merits of the systems and offer the drivers sufficient opportunity to arrive at their sense of IVSS utility and potential benefit.

3. The technologies themselves were not fully debugged by the end of the second survey. This meant that the drivers were not able to report on a set of technologies that were performing up to their design specifications.

Timeline

Figure 5-3 shows the schedule for the training, orientation, interviews, surveys, and the period of system activity (the system was active from December 22, 2001 through March 30, 2002).

	2001 October	November	December	2002 January	February	March	April	May	June
Informed Consent		△							
Training	△								
Orientation		△							
Baseline Interview			△						
1st Internet Survey				△- - - -△					
2nd Internet Survey							△ - △		
Final Interview							△		
System Active			△-	- - - - - - - - - -	- - - - - - - -	- - - - - - -△			

Figure 5-3. Schedule of Events for the Mn/DOT FOT

A Battelle evaluation team member was onsite during the major sessions when drivers received classroom training on the systems throughout the month of October, and he familiarized the drivers with the plan for interviews and Internet surveys. The large number of drivers in different locations with different work schedules required that the training be spread out over several separate occasions.

Data Collection Procedures

Several alternative strategies for collecting data from the drivers were considered, including written surveys, telephone and in-person interviews, and Internet surveys. In-person interviews were implemented because they provided a means of gathering attitudes, opinions, and anecdotal information not easily gathered by other instruments. Battelle selected the Internet approach for the surveys because we felt this would be of interest to the drivers and would motivate them to complete the survey, as well as provide a manageable approach with the expectation of a high participation rate. The purposes of these interviews and surveys are shown in Table 5-7 in the order in which they were administered.

Table 5-7. Scheduled Interviews and Surveys

Data Collection Method	Dates of Implementation	Purpose
First Interview	Dec. 12 – 13, 2001	Gather baseline driver and supervisor attitudes, perceptions and expectations of the systems.
First Survey	Jan. 7 – 27, 2002	Gather baseline information from the drivers on their experiences with technology and their expectations of the systems.
Second Survey	April 2 – 11, 2002	Gather information after deployment of the IVSS technologies regarding driver uses of these systems, effects on driving behavior, and perceptions of benefits.
Second Interview	April 11, 2002	Gather qualitative information on driver and supervisor acceptance of IVSS, and an understanding of any changes in their attitudes and perceptions.

Interviews

Interviews were arranged with the cooperation and active support of Mn/DOT management. At each individual interview, the Battelle representatives explained their role in the project, the reasoning behind the questions and intended use of their responses, and assured the confidentiality of their answers. For each interview, arrangements were made to talk to as many of the drivers as possible. Most of the drivers were interviewed, except for a number of alternate ambulance drivers and the backup state patrol driver. Interviews were conducted with one participant at a time, and they lasted about 40 minutes each.

The discussions were guided by a discussion protocol that listed all of the questions of interest, but the actual discussions were relatively free-flowing and informal. One member of the evaluation team led the discussion while the other took notes. Participants were assured that their names would not be used in any reports, and the resulting discussions were candid and open. Interviews with both the drivers and supervisors were conducted in convenient locations in three garages or the Hutchinson Hospital, although the protocol questions were different for each of these two groups of participants.

Internet Surveys

Internet connections were accessible to each driver through his or her supervisor at their truck station, and this was a relatively low cost, efficient approach to implementing the survey and collecting data from the drivers. The intent was to achieve 100 percent driver participation in the survey, and the Internet approach was judged to offer the best chance of achieving a high response rate. Internet surveys were designed to take about 15 minutes to complete.

Battelle had already developed an Internet survey framework, and it was straightforward to tailor a survey for this IVI FOT, using a set of questions designed for this purpose. The survey was prepared and pre-tested by Mn/DOT using approximately a dozen specialty vehicle drivers who were not affiliated with the Field Operational Test (FOT). Their feedback and comments were used to improve the question wording and the survey presentation over the Internet. The final survey version was made available to the FOT drivers, who were notified to take the survey and given instructions on how to log onto their station computers.

Survey returns were monitored on a regular basis, and drivers were reminded by Mn/DOT management several times of the importance of completing the survey. It is unclear how many drivers were actually available to take the survey, because there remained some uncertainty regarding how many ambulance drivers would actually end up participating in this IVI program, there was some turnover in the drivers participating in the survey, and a few drivers were unavailable to take the survey. For the final Internet survey, only those drivers who had used the systems during a snow event were asked to complete the survey. It was difficult to arrange interviews with all the ambulance drivers, so only those drivers who had used the equipment participated in the final survey and the interviews.

Two state patrolmen participated in the FOT, a primary patrolman assigned to the equipped state patrol car and a back-up patrolman trained in the operation of the equipment who was slated to use the equipped vehicle only when the primary patrolman was not available to perform his duties. The primary patrolman was able to perform his duties throughout the evaluation period, so the back-up patrolman never gained experience with the systems and therefore had no need to participate in the surveys or interviews. The driver participation for each data collection event is shown in Table 5-8.

Data collected at the initial and final time points allowed for descriptive analysis of data on driver expectations, perceptions, and experiences at those time points, and also allowed for a comparative assessment of any changes in responses and perceptions over the time period covered by this evaluation. Data from the same or similar questions asked at both points in time were analyzed to determine any changes in perception over time. Changes in perceptions were examined for groups of drivers (group averages for example) and at the individual level for the ten drivers who participated in both the first and second Internet surveys (to examine any changes in responses by the same person at both time points). In addition, where possible, comparisons between the survey responses and the objective systems data were provided as a way to discern how accurately drivers monitored their behavior and the accuracy of their perceptions of the system's performance.

Table 5-8. Participants in Internet Surveys and Interviews

Driver/Operator Group and Supervisors	Eligible to Participate*	First Internet Survey	Second Internet Survey**	First In-Person Interview	Second In-Person Interview
Snowplow	10	6	8	8	8
Ambulance	15	11	4	3	3
State Patrol	2	1	1	1	1
Supervisors	5	n/a	n/a	4	3
Totals:	**32**	**18**	**13**	**16**	**15**

* The number of eligible drivers and supervisors is estimated to give the reader a sense of the response rate to the surveys and interviews. See the text for further explanation of eligibility. Also, 10 of the drivers/operators responded to each of the Internet surveys, and the rest responded to only the first or second survey. "n/a" = not applicable.

** Only operators who had actual driving experience using the IVSS were asked to complete the second survey.

This evaluation was conducted in parallel with a similar but independent evaluation conducted by the University of Minnesota (2002). Evaluators from both teams met periodically to discuss and coordinate plans for surveying and interviewing drivers, both to enhance the quality and comparability of the two evaluations, and to minimize the burden on the drivers to meet with the evaluators and respond to questions.

Ride-alongs. The Battelle evaluation team desired to participate in "ride-along" observations with some of the drivers in order to witness and document the actual operator interaction with the IVI technologies, reaction to false alarms, and any confusion regarding use of the system. A ride-along would have involved a researcher accompanying the operator of a specialty vehicle on his/her normal route (including snow removal operations) on a not-to-interfere basis and while the driver assistive system (DAS) was activated. Ride-alongs would have been preferable during low-visibility events, but a researcher was not available during the rare times when that occurred during the FOT.

5.3 Operations Data (Incidents, Maintenance, etc.)

Several types of operational data are needed to implement the technical approach. They include driver/vehicle dispatching and route assignments, local weather data, traffic and road conditions, maintenance and repair data, and accident reports.

Dispatching, Weather, and Traffic/Road Condition Data. The driver dispatching and route assignment information was incorporated into the on-board data acquisition system; so, it was not necessary to obtain this information from external data sources. Local weather data, including snowfall depths were made available through the Mn/DOT Metro Division Maintenance operations Snow and Ice Report for 2001-2002, and data on traffic and road conditions were available through Mn/DOT. Because of the limited snowfall and its impact on the safety benefit analysis, there was no need to perform in-depth analysis of the weather and traffic data.

Accident Reports. The State of Minnesota – Department of Public Safety state-mandated Form PS-32003-07 Traffic Accident Report is for police use. It is required for accidents that involve property damage of $1,000 or more, or injury. Local police, sheriff's office or Minnesota State Patrol officers fill it out. It is then is entered into the State of Minnesota Accident Records via data entry. It has codes for accident locations and a determination of the cause of accident. This information (unlinked from a driver's identity) would be of interest in the event of any crashes involving the specialty vehicles during the FOT. However, Battelle understands that there were no crashes or other accident involving the specialty vehicles during the FOT.

Maintenance/Repair Data. Maintenance and repair data would have been used to evaluate the performance and reliability of the IVSS. These records would also be used to identify mitigating factors that may have affected the vehicle and/or driver performance.

During the FOT, University of Minnesota personnel repaired and maintained all of the IVSS equipment. As part of the *Monthly Field Operational Test Status Report*, URS/BRW Company kept the *Design & System Changes/Maintenance/ Complaint Log* (see Appendix A). This log recorded the <u>Date Vehicle first Turned On as Operational</u> as part of the FOT (December 22, 2001 for all 6 specialty vehicles) and other key information as follows:

1. **Driver Assistive System** (22 entries), including Data, Test Vehicle Type, and Modifications Made to Driver Assistive System and Reason for the categories of Record of Design & System Changes and Maintenance Log,

2. **IVI Infrastructure** (4 entries), including Date, Infrastructure Type (tower equipment, weather station, etc.), and Infrastructure Replaced/Changes to Infrastructure for the categories of Record of Design & System Changes and Maintenance Log,

3. **Record of Complaints** (11 entries), including Data Received, Test Vehicle Type, Date Responded/Resolved, and Complaint & Resolution, and

4. **General Problems, Issues, Comments/Notes** (1 entry).

This log gives insight into the different types of problems that were encountered and how they were addressed. It includes items like vehDAQ dll corruption requiring software reloading, loose components, power failures with components, bad connections, etc. None of the problems experienced seems particularly remarkable for the level of complexity involved with the IVSS technologies and supporting infrastructure. The FOT participants appeared to have kept good track of emerging problems and solved them in a timely manner.

5.4 Literature, Historical, and Reference Data

To answer objective 1A.3 (determine the number of crashes, injuries, and fatalities that could be avoided if all snowplows, patrol cars, and ambulances in the United States that operate in areas of reduced visibility were equipped with IVI technologies), Battelle's evaluation approach to determining benefits was predicated upon capturing data local to the test site, then extrapolating that to the larger state of Minnesota, and then to the yet larger population of the combined states in the U.S. that conduct snowplowing. As part of that approach, it was important to obtain information such as how many snowplows operate nationwide and in what states, how many miles they plow or time spent plowing, and what snowfall levels they encounter. Various collateral factors such as the effects of regional differences in terrain, temperature (e.g., melting and freezing after snow clearance), deicing techniques, and visibility (e.g., fog and blowing snow) would also need to be considered. Those types of data are obtained from searches of literature and other references. The extrapolation could then determine the magnitude of the benefit in each state and in all snowplowing states. The literature and reference data actually collected during this FOT were only a start in that process.

In order to extrapolate data that were collected for the area of the TH-7 test corridor to the State of Minnesota, it was necessary to get historical crash data for the test corridor as well as snowplow crash data and weather data for the state of Minnesota. That information could then be used for extrapolation to the larger national perspective.

5.4.1 Literature and Reference Data

Sources in the open literature were reviewed to develop credible estimates of the numbers of snowplow trucks and related vehicles that were currently in use in the United States, and other data relevant to extrapolating observations from Minnesota to other regions. One of the purposes was to use field operational data to predict the safety benefits of certain advanced safety systems installed on heavy snowplow trucks. The technologies were intended to help operators maintain desired lane position and avoid collisions with obstacles during periods of low visibility, using vision enhancement, lateral guidance, and collision warning systems. These IVI systems were expected to allow equipped snowplows to operate when conventional snowplows would not be able to operate (e.g., start earlier following a severe storm, or stay out longer in adverse conditions), and to operate at increased speed without incurring any additional safety risk.

Once the effects of these technologies on safety (i.e., expected increases or decreases in the rate of crashes involving snowplows; effect on numbers of crashes among the general public; effect on public mobility in general) were estimated in the study population, these effects would be converted to monetary values and applied to a formal benefit-cost analysis (BCA) for Mn/DOT. Assuming that comparable safety effects may be realized through wider deployment of the technologies to similar fleets of snowplow trucks, the Mn/DOT data would have been extrapolated or extended from Minnesota to a larger region and, if possible, to all areas of the U.S. where snowplow trucks operate in low-visibility conditions. The greatest benefit in monetary terms is expected to be reduced crashes among the general public.

The four snowplow trucks that were being evaluated in the field, operated in a region extending westward from the Minneapolis-St. Paul metropolitan area. The operating location (home base garage or terminal) and equipment type for each truck were as follows:

- Eden Prairie: International class 33 single axle dump truck, gross vehicle weight (GVW) 56-60,000 lb
- Shakopee: Ford class 35 tandem axle dump truck, "11 yard box," GVW 70,000 lb
- Hutchinson: Ford class 33 single axle dump truck, GVW 55,000 lb
- McLeod County: Sterling class 35 tandem axle dump truck, GVW 75,000 lb.

5.4.1 1 <u>Data Sources and Limitations</u>

Reliable, nationwide data on the numbers of snowplow trucks in operation were not readily available. An informal state-by-state survey was conducted by telephone. Also, a review of the technical and trade literature was conducted, using information published on the internet and elsewhere (e.g., DIALOG). Counts of snowplows were supplemented by information that could be used to infer populations of trucks or to indicate their level of operations, such as lane-miles of highway plowed per year or hours spent in snowplow operation.

Results

Table 5-9 shows the estimated numbers of state-owned snowplows for each of 30 states contacted in the northern and middle U.S. These were the numbers of snowplows reported by representatives of the State DOTs and do not include contractor-owned snowplows. A Battelle interviewer called each state's main DOT information phone number, and was usually transferred to an equipment management area or department. The information requested was the total number of heavy-duty, dump truck-style, state-owned snowplows. Because the emphasis of the Mn/DOT evaluation is on snowplows used on public highways, this survey excluded local (county, township), village or city, and private or contractor-owned snowplows, which may represent a significant number of additional snowplows that could benefit from the IVI technology. It is believed that many states rely on contractor-owned snowplows for some of their snow removal operations.

States that may have snowplows, but that are not listed in Table 5-9 (e.g., California, North Carolina) were either not contacted or were not able to provide information. The State of Massachusetts reported having 4000 state-owned plows, by far the largest number per state in Table 5-9. Rhode Island reported having 95 plows, which was the smallest number.

Table 5-9. Estimated Numbers of State-Owned Snowplows Reported per State

State	Snowplows	State	Snowplows
Alaska	515	New Hampshire	288
Colorado	954	New Jersey	514
Connecticut	620	New York	1,300
Iowa	880	Ohio	1,984
Idaho	398	Oregon	602
Illinois	1,560	Pennsylvania	2,268
Indiana	1,100	Rhode Island	95
Kansas	700	South Dakota	950
Kentucky	800	Utah	717
Massachusetts	4,000	Virginia	2,500
Maine	600	Vermont	245
Minnesota	950	Washington	448
Missouri	1,875	West Virginia	917
Montana	675	Wyoming	400
North Dakota	300	**Total***	**29,790**
Nebraska	635		

*Numbers do not include contractor-owned snowplows

In addition to the telephone survey, the results of which are reported above, Internet web pages and other information sources were used to collect supplemental or confirmatory counts, as follows.

Kentucky. Kentucky reported having 800 state-owned snowplow trucks, plus access to another 148 contract trucks (FHWA 2001b). The figure of 800 matched the phone survey results.

Minnesota. Minnesota DOT reported having 950 snowplows available throughout the state (Mn/DOT 2001). This was comparable with a 1999 report showing the state having more than 830 snowplows (Booz-Allen 1999).

Montana. For the five-year period 1997 to 2001 (fiscal years), the Montana DOT reported plowing an average of approximately 2.75 million miles per year, and spending approximately 170,000 hours plowing per year. This represented an average speed of about 16 mph (Montana DOT 2001).

Ohio. The Ohio DOT had available 1536 trucks with plows, and was responsible for 43,000 lane miles of highways statewide (Ohio DOT 2001). It was not specified on the web site whether these were all state-owned and heavy-duty trucks, or whether contractor and pickup-style plow trucks were included. The telephone survey indicated a higher count of 1984 snowplows.

As an example of the scope of city or local snowplow operations, the Ohio city of Cuyahoga Falls, in the state's lake-effect snow belt near Cleveland (population approximately 50,000) was reported to have 31 snow removal vehicles in use: 7 pickup trucks, 10 one-ton dumps, and 14 five-ton trucks (Lay and Williams 1997).

Nationwide (U.S.). A product manager for one major manufacturer of snowplow trucks, Oshkosh Truck Corporation (Oshkosh, Wisconsin) indicated as a ballpark guess that there were approximately 40,000 heavy-duty snowplow trucks in operation in the U.S., based on annual national sales volume and expected equipment life (Oshkosh 2001).

5.4.1.2 Supplemental Information

Other information was collected relevant to snowplow operations by state. Numbers of lane miles, amount of annual snowfall, and demographic and geographic data were collected, for possible use in modeling the expected safety benefits nationwide based on information observed in Minnesota.

Lane Miles, Census Population, and Land Area by State

Table 5-10 shows the number of lane miles of rural and urban roadway in 1999 in each of the 50 states plus D.C. These data come from the Federal Highway Administration's annual publication, *Highway Statistics: 1999* (FHWA 2001a). The FHWA website has many tables containing information on highway lengths and characteristics. This information was located on the "Selected Measures for Identifying Peer States" table. The table also shows the census population totals per state as of April 2000, and each state's total land area as of 2000, both from the Census Bureau's web site (2001a; 2001b).

Snowfall Amount by Weather Station

The data summarized in Table 5-11 represent the annual average snowfall for 248 weather stations throughout the U.S. These data were downloaded from the National Oceanic & Atmospheric Administration's National Virtual Data System website (NOAA 2001) and have been extracted from the Normals, Means, and Extremes table contained in the *Local Climatological Data Annual Summary*, published by the individual stations, and summarized by NOAA. The numbers in Table 5-11 represent an average of the values for each of the weather stations in each state, as well as the total number of stations represented by each average.

Table 5-10. Lane Miles, Population, and Land Area by State

State	Rural Lane Miles	Urban Lane Miles	Population (2000)	Total Land Area (square miles)
Alabama	150,323	44,847	4,447,100	50,744
Alaska	21,724	3,950	626,932	571,951
Arizona	77,180	39,722	5,130,632	113,635
Arkansas	175,281	22,757	2,673,400	52,068
California	173,244	195,188	33,871,648	155,959
Colorado	144,357	32,078	4,301,261	103,718
Connecticut	18,478	25,878	3,405,565	4,845
Delaware	7,970	4,530	783,600	1,954
Dist. of Columbia	0	3,771	572,059	61
Florida	140,525	110,785	15,982,378	53,927
Georgia	177,665	61,625	8,186,453	57,906
Hawaii	4,762	4,440	1,211,537	6,423
Idaho	85,187	8,675	1,293,953	82,747
Illinois	207,732	80,771	12,419,293	55,584
Indiana	150,911	42,688	6,080,485	35,867
Iowa	209,788	21,660	2,926,324	55,869
Kansas	249,907	22,836	2,688,418	81,815
Kentucky	129,435	24,384	4,041,769	39,728
Louisiana	96,295	31,468	4,468,976	43,562
Maine	40,764	5,568	1,274,923	30,862
Maryland	33,574	33,056	5,296,486	9,774
Massachusetts	25,158	49,266	6,349,097	7,840
Michigan	186,960	68,629	9,938,444	56,804
Minnesota	235,425	35,343	4,919,479	79,610
Mississippi	133,999	17,305	2,844,658	46,907
Missouri	215,905	34,887	5,595,211	68,886
Montana	136,675	5,502	902,195	145,552
Nebraska	176,862	11,373	1,711,263	76,872
Nevada	61,493	13,542	1,998,257	109,826
New Hampshire	25,053	6,211	1,235,786	8,968
New Jersey	24,687	53,077	8,414,350	7,417
New Mexico	110,916	13,890	1,819,046	121,356
New York	146,792	91,978	18,976,457	47,214
North Carolina	156,507	51,592	8,049,313	48,711
North Dakota	171,347	4,010	642,200	68,976
Ohio	170,140	73,827	11,353,140	40,948
Oklahoma	202,261	30,049	3,450,654	68,667
Oregon	114,021	23,382	3,421,399	95,997
Pennsylvania	174,654	74,038	12,281,054	44,817
Rhode Island	2,770	10,043	1,048,319	1,045
South Carolina	112,068	23,938	4,012,012	30,110

State	Rural Lane Miles	Urban Lane Miles	Population (2000)	Total Land Area (square miles)
South Dakota	164,590	4,350	754,844	75,885
Tennessee	142,723	40,550	5,689,283	41,217
Texas	452,220	185,592	20,851,820	261,797
Utah	70,323	16,314	2,233,169	82,144
Vermont	26,452	2,893	608,827	9,250
Virginia	108,344	43,905	7,078,515	39,594
Washington	126,358	41,155	5,894,121	66,544
West Virginia	67,798	6,974	1,808,344	24,078
Wisconsin	193,794	36,603	5,363,675	54,310
Wyoming	50,652	5,034	493,782	97,100

Table 5-11. Average Annual Snowfall in Inches by State

State	# of Stations	Average Snowfall (in.)
Alabama	5	1.38
Alaska	22	80.34
Arizona	3	37.33
Arkansas	3	5.87
California	7	51.10
Colorado	5	38.60
Connecticut	2	37.55
Delaware	1	20.70
Dist. of Columbia	2	19.75
Florida	3	0.07
Georgia	6	1.22
Hawaii	4	0.00
Idaho	3	26.17
Illinois	6	27.43
Indiana	4	35.55
Iowa	4	35.30
Kansas	5	23.26
Kentucky	4	16.78
Louisiana	4	0.55
Maine	2	91.20
Maryland	1	21.10
Massachusetts	3	56.63
Michigan	9	80.03
Minnesota	5	58.10
Mississippi	3	1.67
Missouri	5	20.08

State	# of Stations	Average Snowfall (in.)
Montana	6	50.47
Nebraska	8	31.70
Nevada	5	27.28
New Hampshire	2	161.75
New Jersey	2	21.70
New Mexico	3	14.90
New York	9	60.88
North Carolina	6	6.87
North Dakota	3	42.40
Ohio	8	40.03
Oklahoma	2	9.65
Oregon	8	23.44
Pennsylvania	8	42.90
Rhode Island	2	28.10
South Carolina	3	2.93
South Dakota	4	39.68
Tennessee	5	9.30
Texas	16	3.56
Utah	2	51.80
Vermont	1	78.80
Virginia	5	14.28
Washington	7	19.93
West Virginia	4	49.53
Wisconsin	4	46.03
Wyoming	4	76.95

The snowfall data in Table 5-11 are limited by the locations of the various weather stations. For example, the number reported in Table 5-11 for New Hampshire was most likely inflated due to the fact that one of the two weather stations in that state is located on a mountain. According to the U.S. Census Bureau, citing NOAA information from the Concord, NH, airport over the past 57 years, average annual snowfall there is 64 inches (U.S. Census 2000). Likewise, average annual snowfall for Burlington, VT, is 78.3 inches.

Application of Snowplow Data and Related Information to Safety Benefits Estimation

State-owned snowplow populations and related information were expected to be used in estimating national safety benefits that would have been accrued if the collision-avoidance technologies tested in Minnesota were to be adopted on heavy-duty snowplows throughout the United States. Estimates of the system's benefit would have been obtained from the FOT data. The data described here would have been used in conjunction with those estimates to extend the benefits estimates to as much of the U.S. as possible. This would be used to estimate the total number of accidents that could be avoided if all snowplows nationwide were equipped with these safety systems.

The benefits of these safety systems would have been assessed in reference to an exposure measure. Ideally this exposure measure would have been the number of vehicle miles traveled in low-visibility conditions. To obtain this exposure measure, we would need the number of lane miles plowed, including the weather conditions under which the plowing was done. Of particular value would be information on the visibility conditions along with the snow depth for each lane mile plowed.

Because these data were not available, supplemental data such as that presented above would have been used to estimate this number. The data that we found would have allowed us to obtain very rough estimates of these needed inputs. The major limitations of these data were (1) the lack of vehicle miles traveled for snowplows and (2) only univariate data. Total average snowfall and lane miles of highway would have been used as proxies for lane miles plowed, and we had no data on visibility. Because of this we would have had to assume that visibility levels in the rest of Minnesota and in other states were the same as those observed in the test corridor. Alternatively, wind-speed data could have been used in conjunction with terrain type as a proxy for visibility. The problem with this approach is that we would not have been able to validate any methodology developed for estimating visibility.

5.4.2 Historical Population Crash Statistics

There were three sources of historical crash and safety incident data that were provided for use in the evaluation. These included (1) data on crashes of all types of vehicles along TH-7 during a five-year period, (2) snowplow crash reports during a six-year period, and (3) statistical summary information on snowplow crash data during a ten-year period.

<u>TH-7 Crash Reports</u>
Mn/DOT provided Trunk Highway 7 crash data generated from police reports, for crashes within the nearly fifty-mile TH-7 test section. These data included 1,513 crashes from the five-year

period January 1995 through December 1999. The data contained 22 variables related to the crash scene, such as weather and road conditions.

Examples of the variables include:

- Accident type,
- Vehicle type,
- Traffic control device,
- Relationship to intersection,
- Light conditions,
- Weather conditions,
- Pre-accident actions, and
- Contributing factors (two per vehicle).

The responding police officer determined two variables as contributing factors for each crash. These data did not contain information on crashes involving snowplows. They may have be used to aid in the estimation of the safety benefits of cleared roads to the general public, however.

A brief summary of these data is presented in Table 5-12.

Table 5-12. Summary of Snow Related Accidents on Trunk Highway 7

Winter Conditions	Frequency	Percent of Total
Total	1513	-
During Winter Months	904	59.8%
While Snowing/ On Snowy Roads	267	17.7%
Weather Contributed	99	6.5%
Snowy Roads Contributed	92	6.1%

These data were not sufficient to determine the impact of snowplowing on public safety. It was anticipated that additional information from the literature would be needed.

<u>Snowplow Crash Reports</u>

Mn/DOT provided 320 individual snowplow crash reports from 5 districts and 43 counties, during the six-year period January 1995 to December 2000. These reports contained data related to the crash scene, weather and road conditions, etc. They were completed by the Mn/DOT snowplow driver or representative and included a brief description of the crash given by the driver. Along with outside research, these reports were used to determine the types of driving conflicts that were relevant to this FOT and to develop estimates of the probability that a driving conflict precedes a crash when a snowplow is not equipped with IVI technologies (see Section 6.1.2).

Table 5-13 summarizes the snowplow crash reports by district and year. (Note: M stands for Mn/DOT's Metropolitan District).

Table 5-13. Mn/DOT Crash Reports by Fiscal Year and District

District	1995	1996	1997	1998	1999	2000	2001
3	10	21	28	11	4	2	NA
6	2	9	8	5	7	NA	NA
8	0	9	14	5	5	5	2
M	NA	NA	26	24	31	30	46
4	0	0	12	2	2	NA	NA

<u>Statistical Summaries of Snowplow Crashes</u>

Mn/DOT provided Battelle with statistical summaries of statewide snowplow crash data. These were specific totals provided by Mn/DOT District Offices, which submitted them to Mn/DOT's Central Office. Each district reported monthly totals for the numbers of accidents, personal injuries, windshield claims, and rear-end accidents. These data would have been used as an aid in the extrapolation of results to the entire state of Minnesota.

Table 5-14 contains selected annual averages, by district, for fiscal years 1991 through 1999.

Table 5-14. Selected Annual Averages from Mn/DOT Crash Database

District	Personal Injuries	Accidents	Rear-End Accidents	Windshield Claims
1	2.38	14.33	5.11	5.86
2	1.22	6.89	2.00	2.14
3	1.89	13.89	4.89	1.57
4	6.67	7.67	2.67	1.00
M	3.67	46.00	9.11	19.00
6	1.00	11.67	3.25	2.57
7	0.50	4.78	2.56	1.00
8	1.13	7.67	1.33	1.86

'Personal Injuries' were the number of injuries from accidents involving a snowplow. 'Accidents' represented the number of accidents involving a snowplow that resulted in Mn/DOT filling out a crash report. 'Rear-End Accidents' referred to accidents where a snowplow was rear-ended by another vehicle. 'Windshield Claims' referred to the number of claims reported by motorists whose windshields were damaged by snowplows.

Fleet Crash Statistics and Safety Data from Mn/DOT and other Fleets

One of our original evaluation objectives was to estimate the number of crashes avoided if all similar snowplows were equipped with the IVSS. Thus, we would have needed to determine potential target fleets, groups of similar snowplows, to which our findings could be extrapolated. In order to extrapolate our results, the number of snowplows, the type of roadway plowed, and the relevant weather data were needed for each target fleet. The following would have been some potential sources for these data, including their role in the extrapolation.

Weather Data

Data obtained from the National Climatic Data Center were used to obtain a reasonable exposure measure since a historical value for vehicle miles traveled was not available for the Mn/DOT snowplows. These data contained information regarding snowfall totals, number of days with snow, and temperature, and were available for all other states to help facilitate extrapolating results. These data were collected from 205 weather stations in Minnesota from October 1993 through April 2001. Some of the relevant data values are summarized in Table 5-15.

Table 5-15. Minnesota Winter Snowfall Summary

Season	Number of Days With Snow	Total of Daily State Average Snowfall (in)
93-94	145	189.93
94-95	135	147.22
95-96	170	260.39
96-97	162	277.24
97-98	142	139.88
98-99	126	180.62
99-00	117	112.21

The locations of the 205 weather stations are shown in Figure 5-4.

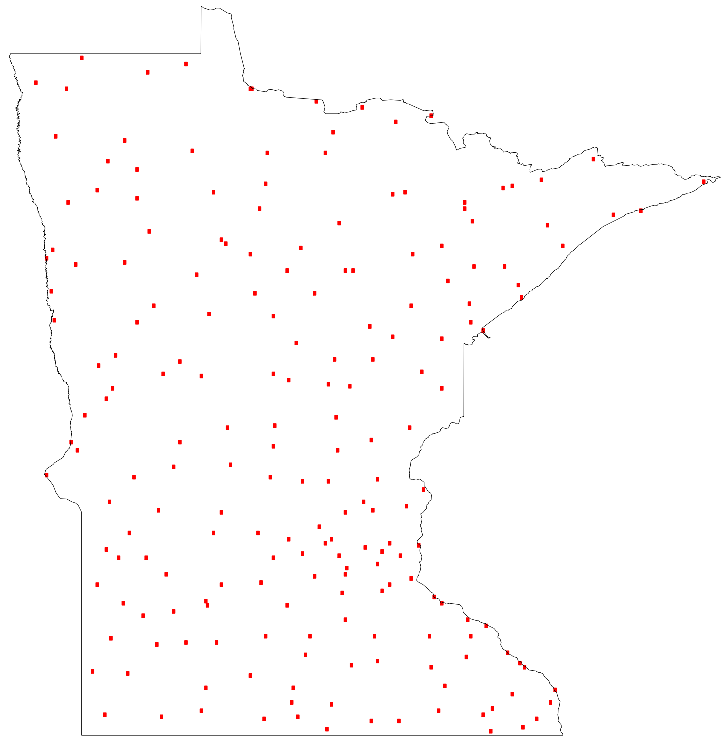


Figure 5-4. Minnesota Weather Stations

Federal Highway Administration -- Highway Statistics

Every year the Federal Highway presents summary statistics of general interest on motor fuel, motor vehicles, driver licensing, highway-user taxation, State highway finance, highway mileage, and Federal aid for highways. These data are available online through the Federal Highway Administrations web page, and contain information on the number of lane miles in each state broken down into several groupings. These data would have been used in conjunction with the weather data to develop an exposure measure for estimating the benefits of the IVSS. This exposure measure would then be used to extrapolate the results to fleets that operate in areas outside of the test zone.

5.5 University of Minnesota Validation Tests

The Mn/DOT Partners published the *Draft Validation Report, Intelligent Vehicle Initiative Specialty Vehicle Field Operational Test* in March 2002. The stated purpose of the validation report was "to verify that the components from which the driver assistive system was built operate properly so that the system as a whole functions as designed. Within the Validation Report was a range of observations from a simple observation of functionality to detailed analyses of complex technical matters.

This report determined that the components of the IVSS in general were adequately meeting all system requirements relating to their performance. The side-looking radar was not available at the time of the draft Validation Report so its data were pending. The Validation Report noted problems that were experienced with the DGPS that eventually required replacement of receivers, and it also discussed some magnetic tape failures caused by snowplow blade damage and other factors.

6.0 ANALYSIS METHODS

This section more completely describes the analyses of the types of data that would have been collected and analyzed during the FOT. For each type of data available we describe the data collection process employed and discuss how the data would have been used to test specific hypotheses and address evaluation objectives.

6.1 Safety Benefits Analysis

Discussion

This section contains a detailed discussion of the safety benefits analyses that were planned for the Mn/DOT FOT. There were four main objectives that fell under the heading of safety benefits that Battelle planned to answer:

Objective 1A.1 Determine if drivers drive more safely,

Objective 1A.2 Determine if drivers have fewer driving conflicts and smaller crash probabilities,

Objective 1A.3 Estimate the reduction in crashes, injuries, and fatalities nationwide if all such fleets are equipped, and

Objective 1A.4 Determine whether improved snow removal impacts public safety.

We describe the analyses that would have been performed in order to test specific hypotheses and achieve the goals and objectives. Section 5 includes the System Performance Assessment, the Safety-Benefits Analysis and the Benefit-Cost Analysis – three significant analyses that were carried out as part of Battelle's methodology. The FOT did not generate useful data on snowplow usage, road closures, snowplowing efficiency/productivity, environmental impacts, or crash reduction.

The majority of the planned data analysis to address safety benefits was in support of estimating the reduction in conflict rates and crash probabilities (Objective 1A.2). Exploration of other empirically observed changes in driving behaviors due to the data that were collected in the winter of 2001-2002 was not sufficient to achieve these objectives. Thus, the purpose of this section is not to present the finding of safety benefits, but instead to present the methodology that Battelle was going to use to evaluate the safety benefits of the IVSS had there been enough low-visibility data collected. This section also presents the results of the analysis that was completed on the data to show how the data collected fits into this analytical framework. This approach allows others, who attempt to do a similar analysis of FOT data, to use the methodological framework developed for the Mn/DOT FOT and also benefit from the conflict identification algorithms that were developed on the data that were collected during the FOT.

6.1.1 Determine if Drivers Drive More Safely

The planned analyses included comparisons of statistics calculated from the onboard driving data made between specialty vehicles with the IVSS on and with the IVSS off. These comparisons could provide objective and quantitative information on the effect of the side-looking and forward-looking radar systems, the head up display and the lane keeping system as a bundled system (control vs. test). However, the degree to which these comparisons provide information on the changes in behavior due to individual systems depends on specific assumptions concerning how individual systems affect or do not affect certain driving behaviors. The experimental design for this FOT was not set up to test the performance of individual systems. In this FOT all systems were integrated and operated together. To evaluate the individual systems they would each have to be operated for some period of time by themselves.

For lane keeping behavior, speed, average following intervals and hard braking event summaries would be created from the driving data with and without the systems on. Lane keeping behavior, speed, average following interval, hard braking events, number of alarms and conflict rates were proposed as surrogate safety benefits. If there is more than one target being tracked, the average following interval would be calculated for the target that has the shortest following interval and is in the path of the specialty vehicles. Lane keeping would be some measure of variability, mean squared error perhaps, computed based on the difference between the specialty vehicle's position and the lane centerline. This measure would be computed for periods of time when it can be determined that the specialty vehicle is traveling in a specific lane. Hard braking events would be ones for which the deceleration of the specialty vehicle was greater than some threshold for a pre-specified duration. All other measures are self-explanatory. Changes in the rates of occurrences of any of these events that could be attributed to the IVSS could indicate safer or possibly less safe operation. Below we discuss what was planned in each of these areas and what progress was made with the data available.

For all these analyses, rates per some exposure measure would need to be computed. The measures of exposure that were considered were vehicle miles traveled (VMT), lane miles plowed (for snowplows), and various measures of snowfall and road conditions in combination with the visibility measures recorded from the weather stations along the test corridor. The ideal measure of exposure would need to be reduced to the amount of exposure under low-visibility conditions, since this is the only time that the IVSS is designed to aid the drivers. For all our analyses that we were able to do with the data available we computed rates per VMT and presented the results for the different visibility categories recorded at the weather stations.

The distributions of these computed variables would be compared for system on time and system off time during low-visibility conditions. Any statistically significant differences for these distributions between the groups would be investigated further to determine if the change in driving behavior was an indication of safer driving or not. Another part of this investigation would be to explore conditional analyses to determine if the differences could be attributed to some other cause other than the system. For instance, fewer events of a specific type may be observed on the test roads than on the control roads. However, this reduction in events may be due to some other factor like roadway type and not the system.

The overall number of warnings or alarms given to the driver, or even the distribution of the alarm levels, are indicative of driving behavior: safer driving is assumed to be characterized by fewer alarms or alarms of lower levels. For this FOT the actual occurrences of alarms were not recorded. The only thing that can be determined from the data collected is whether the conditions for an alarm were met. The exact algorithms are proprietary to the University of Minnesota and Battelle was not able to obtain the exact algorithms used to trigger the alarms. Thus, when the alarms went off cannot be determined with certainty. The first step of this analysis would be to recreate from the data available, the times when any alarm should have sounded. The rates of the different alarms would be compared for system on time and system off time during low-visibility conditions, and alarm rates that were significantly lower for the system on time would be an indication that the IVSS helped the specialty vehicle drivers drive safer in low-visibility conditions.

The other hypothesis of interest under this objective is whether the specialty vehicles would have fewer near misses or driving conflicts with the IVSS than without. Driving conflicts are safety-critical driving situations encountered by snowplows, such as *snowplow is traveling in low visibility conditions and travels over the edge of the road*. One resolution to a driving conflict is a crash. The other resolution is that the driver makes some corrective action that avoids a crash and removes the safety-critical driving situation. Driving conflicts serve as surrogate safety measures and as stepping-stones for estimating the number of crashes, injuries, and fatalities. The first step in this analysis is to define what constitutes a driving conflict (see Section 6.1.2). This analysis would be repeated for each crash type being considered. Then the rate of conflicts per exposure unit (number of conflicts divided by the total exposure) would be compared between system on time and system off time during low-visibility conditions. The specifics of what defines a conflict and how they were identified in the FOT data are described in the next section. Differences in rates among the groups that are statistically significant indicate whether or not the IVSS have made driving safer for specialty vehicle operators driving in low-visibility conditions, if sufficient.

6.1.2 Determine if Drivers Have Fewer Driving Conflicts and Smaller Crash Probabilities

The purpose of the crash avoidance analysis is to address hypotheses under Objective 1A.2 regarding fewer driving conflicts and smaller crash probabilities for snowplows, ambulance and squad cars. Generally, these hypotheses address reductions in driving conflicts, crashes, or severity of crashes due to the use of IVSS. There are four key aspects to the crash avoidance analysis:

1. Identifying crash types and driving conflicts relevant to the FOT being evaluated,
2. Predicting widespread safety benefits from FOT driving data containing few or no crashes using the driving conflicts,
3. Identifying driving conflicts in FOT driving data, and
4. Predicting crash probabilities in specific driving conflicts using analytical models.

Battelle's *Safety Benefits Estimation Methodology for the Intelligent Vehicle Initiative Generation 0 Field Operations Tests* (draft revision 2, November 22, 2000) provides details on all four aspects of the crash avoidance methodology.

6.1.2.1 Overview of Safety Benefits Estimation Methodology

Estimating the reduction in the probability of a rear-end crash, single-vehicle roadway departure crash, and lane-change/merge crash under conditions encountered during the FOT is the primary emphasis of the assessment of safety benefits. The proposed methodology is similar to the approach developed by the National Highway Transportation Safety Administration (NHTSA) and Federal Highway Administration (FHWA) of the USDOT, together with the Volpe National Transportation Systems Center (Najm 1999, Najm and daSilva 1999a, 1999b, 2000).

With data collected for a very limited number of low-visibility driving miles for the specialty vehicles, and no crashes during the FOT, the data were not sufficient to discern statistically significant differences in crash probabilities. Thus, the methodology to estimate reduction in crash probability cannot rely on analysis of crash data. Instead, the proposed methodology partitions all crashes according to the *driving conflict* preceding each crash, and then looks simultaneously for a reduction in exposure to driving conflicts (exposure ratio) and in the chance of a crash once a driving conflict has occurred (prevention ratio). *Driving conflicts* are defined to be particular safety critical driving scenarios, which precede crashes and are defined by the dynamic conditions of the test vehicle and proximate vehicles. For example*, "snowplow is traveling at a constant speed and encounters a lead vehicle traveling at a lower speed"*. All crashes are preceded by a driving conflict, but all driving conflicts do not necessarily result in a crash, as they are sometimes resolved before a crash occurs. Driving conflicts, by definition, are not as rare as crashes, and a significant number are anticipated in the miles driven in the FOT. Thus, the probability of a driving conflict can be evaluated empirically with the onboard driving data.

Based on first principles, the potential reduction in probability of a rear-end crash under conditions encountered during the FOT, R, is:

$$R = [P_{wo}(C) - P_w(C)] \qquad (1)$$

where C is a crash, $P_{wo}(C)$ is the crash probability per FOT exposure unit, without the IVSS and $P_w(C)$ is the matching crash probability for vehicles equipped with the IVSS. While $P_{wo}(C)$ could be estimated from Minnesota historical specialty vehicle crash data, $P_w(C)$ is unknown.

As illustrated by Figure 6-1, normal driving may be partitioned into multiple driving conflict states and a no-conflict state. The parallel lines in the upper left area of the normal driving space indicate the region of normal driving in which crashes can occur. Not all driving conflicts result in a crash. These lines can be thought of as contours of constant probability of a crash, i.e., at the lowest line the probability that the driving conflicts on the line would result in a crash is perhaps 0.1, at the next line perhaps 0.2. Since in this paradigm driving conflicts precede crashes, ratios of incidence of driving conflicts for vehicles with and without IVSS provide measures of change in exposure to the possibility of a crash.

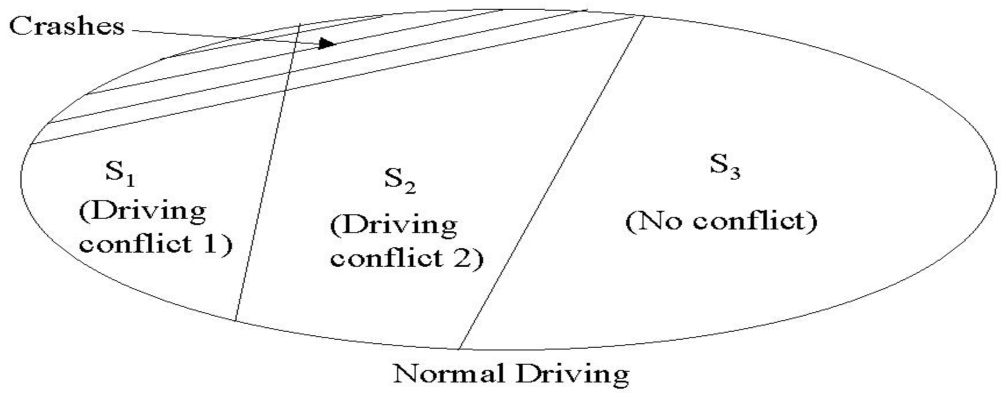


Figure 6-1. Partitioning Normal Driving into Driving Conflicts

Algebraic manipulation of Equation (1), following the rules of conditional probability, yields the **Benefits Equation**:

$$R = P_{wo}(C) \times \sum_i P_{wo}(S_i \mid C) \times [1 - \frac{P_w(C \mid S_i) \times P_w(S_i)}{P_{wo}(C \mid S_i) \times P_{wo}(S_i)}], \quad (2)$$

where S_i are the driving conflicts, which partition the normal driving space (Figure 4-3). The conditional probability $P_w(C \mid S_i)$ is the probability that a crash of a particular type occurred with the IVSS in use, given that driving conflict S_i occurred. $P_w(S_i)$ is the probability that driving conflict S_i occurred with the IVSS in use. Quantities subscripted with "wo" have the same interpretation, but for driving when the IVSS is off. The probability that driving conflict S_i occurred prior to a crash given that a crash occurred, $P_{wo}(S_i \mid C)$, is also required in the Benefits Equation.

The quantities $P_w(S_i)$ and $P_{wo}(S_i)$, probabilities of driving conflicts S_i with and without an IVSS, respectively, can be estimated from the onboard driving data. Mathematical models and onboard driving data are necessary to estimate $P_w(C \mid S_i)$ and $P_{wo}(C \mid S_i)$, the probability of a crash given that driving conflict S_i has occurred with and without an IVSS, respectively.

Values for $P_{wo}(S_i \mid C)$ can be obtained from available historical data on specialty vehicle crashes. Alternative $P_{wo}(S_i \mid C)$ can be partitioned like $P_w(S_i \mid C)$ and estimated from FOT data.

There are two key ratios in the Benefits Equation, namely $\frac{P_w(S_i)}{P_{wo}(S_i)}$ and $\frac{P_w(C \mid S_i)}{P_{wo}(C \mid S_i)}$. The first ratio is the **Exposure Ratio**: the ratio of exposure to driving conflicts with and without an IVSS. Values of this ratio less than 1 indicate that an IVSS would reduce exposure to potential crash situations. The second ratio, the prevention ratio, measures the efficacy of an IVSS at preventing crashes after a particular driving conflict has occurred. Again, if this ratio is less than 1, safety benefits can be inferred. The Benefits Equation is a robust approach to benefits estimation because each of the ratios used in computing benefits is based on a numerator and a denominator obtained by a consistent approach. The two hypotheses considered under this objective would be evaluated using estimates of the exposure and prevention ratios.

The first step is to determine which driving conflicts should be looked for in the driving data. This is determined by analyzing historical crash data to determine what driving conflicts precede crashes involving specialty vehicles. Then the driving conflicts must be found in the FOT data for control driving and test driving. These results are combined to estimate the exposure ratio. Finally, the prevention ratio is estimated by computing the probability of a crash for each driving conflict identified. These algorithms and how the results are combined to estimate the benefits will be discussed in more detail in the next sections.

6.1.2.2 Definition and Identification of Driving Conflicts

The first three hypotheses for Objective 1A.2 relate to changes in the probability of a conflict for the different crash types under the assumption that fewer driving conflicts is an indication of safer driving. The probability of a driving conflict, $P\,(S_i)$, is calculated as the number of driving conflicts identified within the onboard driving data of a particular vehicle group divided by the exposure unit that is chosen for that group. This quantity must be calculated for control driving and test driving. The exposure ratios comparing the control driving to the test driving would serve to address these hypotheses. The methodology to develop and identify driving conflicts in the FOT data is described below.

The analysis of the available historical snowplow crash data was completed during the development of the safety benefits methodology. This was done in order to define the driving conflicts commonly encountered by operators of specialty vehicles. Battelle's Safety Benefits Estimation Methodology document listed four crash types that were expected to be the focus of the Mn/DOT FOT. These crash types were:

- Specialty vehicle Rear-Ends Other Vehicle (Rear-end (Specialty vehicle))
- Single Vehicle Roadway Departure (SVRD)
- Side Obstacle Detection (Lane Change/Merge)
- Other Vehicle Rear-Ends Specialty vehicle (Rear-end (Other Vehicle))

Because this FOT originally intended to test two types of rear-end collision technologies, rear-end collisions would be broken into two subsets, those in which the snowplow rear-ends another vehicle, and those in which another vehicle rear-ends the snowplow.

In order to develop a list of driving conflicts relevant to snowplow crashes, the variables on the snowplow crash reports, generated at the scene of accidents by trained law enforcement personnel, were used to group the crash reports in several ways.

First, the crash reports were broken down by the "Type of Accident" variable. This breakdown is summarized in Table 6-1.

Table 6-1. Paper Crash Reports by Accident Type

"Type of Accident"	Number of Crashes
Motor Vehicle On Same Roadway	146
Motor Vehicle On Separate Roadway	10
Parked Motor Vehicle	26
Pedestrian	2
Fixed Object	20
Falling Object	6
Overturn	4
Not On Form	2
Other	22
Unreadable	68
Blank	14
Total	**320**

A breakdown of this nature is not enough to adequately classify the accidents into the four crash types listed above as being the focus of this FOT. There were 146 crash reports that involve a motor vehicle traveling on the same roadway. Each of the crash types listed above could involve a motor vehicle on the same roadway. In order to further examine the crash reports another variable needs to be examined. One such variable is the "Pre-Accident Action" field, which contains information on the actions of the snowplow immediately prior to the accident. Table 6-2 summarizes this breakdown.

Table 6-2. Pre-Accident Actions for Targeted Accident Type

Pre-Accident Action (Snowplow)	Number of Accidents
Going Straight Ahead/Following Roadway	128
Wrong Way Into Opposing Traffic	3
Making Right Turn On Red	1
Making Right Turn	6
Making Left Turn	11
Making U-Turn	5
Starting From Parked Position	3
Starting In Traffic	1
Slowing In Traffic	1
Stopped In Traffic	9
Parked Legally	2
Avoiding Vehicle/Object in Road	3
Changing Lane	3
Overtaking/Passing	2
Merging	2
Backing	10
Stalled	1
Other/Unreadable/Blank	129
Total	**320**

This breakdown lists 128 crash reports that involved a motor vehicle on the same roadway, which again is not a detailed enough breakdown to classify the crash reports into crash types. Next the direction of the two vehicles was examined. Table 6-3 summarizes the results.

Table 6-3. Direction of Vehicles

Direction of Two Vehicles	Number of Accidents
Same	156
Perpendicular	29
Opposing	21
Blank/Unreadable/NA	114
Total	**320**

This breakdown again does not offer enough classifications to adequately classify the crash reports into the four crash types listed above. For example, the grouping of accidents in which the two vehicles are traveling in the same direction could include accidents falling into all four of the crash types of interest in this FOT. Since the coded variables alone were not sufficient to classify the crash reports into the four crash types of interest a more detailed examination of each crash report was done.

To classify each crash report, the driver's written descriptions, and the multiple variables examined above were used to determine the appropriate grouping of the report into one of the four crash types of interest. After examining all the crash reports a final grouping of crash types was developed and is summarized in Table 6-4.

Table 6-4. Crash Reports by Crash Type

Crash Type	Number of Crashes	Percent of Total
Rear-End (Snowplow)	30	9.4%
SVRD	64	20.0%
Side Object Detection	62	19.4%
Rear-End (Other Veh.)	62	19.4%
Other Accidents	69	21.5%
Unidentified	33	10.3%
Total	**320**	**--**

"Other Accidents" refers to crash reports that did not fall into the other four focus categories. The "Unidentified" classification refers to crash reports that contained too many blank or unreadable variables to allow for a proper classification.

The crash reports within each grouping were then further analyzed to develop a list of driving conflicts that typically lead to each crash type. These driving conflicts would be used to identify driving situations that generally precede a particular crash type. These conflicts are grouped by the resulting crash type, and defined in terms of the first harmful event, or the first sign of an impending accident. Because of the anticipated effect of the IVSS, it is these situations that would be the focus of the analysis. The analysis would attempt to determine whether the safety systems aid the driver in his corrective actions and therefore reduce the number of crashes resulting from a snowplow entering a given driving conflict. The safety systems may also prevent the snowplow from entering the driving conflict, and therefore reduce the number of crashes. The list of dominant driving conflicts is not meant to be a complete list of all possible driving conflicts, but instead a list of all driving conflicts, within the four target crash types, that are mitigated by the IVSS, and have been observed in the historical data. The final list of dominant driving conflicts is presented in Table 6-5.

Table 6-5. Dominant Driving Conflicts

Crash Type	Driving Conflicts	Number of Crashes	Percentage of Crash Type	Percentage of Total
Rear-End (S).1	Snowplow is traveling at a constant speed and encounters a lead vehicle traveling at a lower speed	5	16.7%	1.6%
Rear-End (S).2	Snowplow is decelerating and encounters a lead vehicle	0	0.0%	0.0%
Rear-End (S).3	Snowplow was changing lanes or merging and encounters a lead vehicle traveling at a lower speed	0	0.0%	0.0%
Rear-End (S).4	Snowplow is traveling at constant speed and can not decelerate due to poor road conditions	8	26.7%	2.5%
Rear-End (S).5	Snowplow is traveling at constant speed and can not see lead vehicle due to poor visibility	1	3.3%	0.3%
Rear-End (S).6	Snowplow encounters a stopped vehicle in its lane	16	53.3%	5.0%
SVRD.1	Snowplow is traveling at a constant speed and can not see road due to poor visibility	0	0.0%	0.0%
SVRD.2	Snowplow is traveling at constant speed and travels off the edge of the road	2	6.7%	0.6%
SVRD.3	Snowplow is traveling at constant speed and encounters an object buried in the snow	3	10.0%	0.9%
SVRD.4	Snowplow is traveling at a constant speed and encounters object in road.	25	83.3%	7.8%
Lane-Change/Merge.2	Two vehicles are traveling in the same direction and snowplow encroaches into the other vehicle's lane in order to change lanes or merge	4	5.8%	1.3%
Lane-Change/Merge.3	Two vehicles are traveling in the same direction and the other vehicle encroaches into the snowplow's lane while the snowplow is traveling at constant speed.	36	52.2%	11.3%
Lane-Change/Merge.4	Two vehicles are traveling in the same direction and snowplow encroaches into the other vehicle's lane while traveling at constant speed	1	1.4%	0.3%
Lane-Change/Merge.5	Snowplow is traveling at a constant speed and plow blade extends into adjacent lane	21	30.4%	6.6%
Lane-Change/Merge.6	Snowplow is accelerating from a stopped position and encounters a vehicle that was unseen due to blind spot.	7	10.2%	2.2%
Rear-End (OV).1	Snowplow is stopped in road	8	12.9%	2.5%
Rear-End (OV).2	Snowplow is traveling at a constant speed slower than that of a following vehicle	26	41.9%	8.1%
Rear-End (OV).3	Snowplow is decelerating when encountered by a following vehicle	9	14.5%	2.8%
Rear-End (OV).4	Snowplow is traveling at constant speed and following car can not decelerate due to poor road conditions	4	6.5%	1.3%
Rear-End (OV).5	Snowplow is traveling at constant speed and following car can not see snowplow due to poor visibility	15	24.2%	4.7%
Other Accidents.1	Snowplow is backing and encounters another vehicle.	19	95.0%	5.9%
Other Accidents.2	Snowplow is backing and encounters roadside furniture.	1	5.0%	0.3%

6.1.2.3 Identification of Driving Conflicts

With the driving conflicts clearly defined above, the next step in the Safety Benefits Estimation Methodology is to identify driving conflicts within the on-board engineering data collected during the FOT. To identify a driving conflict in the engineering data, a function, or identification algorithm, of measured vehicle dynamic parameters is applied. When the value of the function is above some threshold, a driving conflict is identified. Both the identification function and the appropriate threshold must be specified. $P_w(S_i)$ is calculated by applying the function to the onboard driving data from the test vehicles, counting the number of times the threshold is exceeded, and dividing that quantity by the exposure measure for that group. The quantity $P_{wo}(S_i)$ is calculated similarly using the FOT data from the control driving.

6.1.2.3.1 Rear-End Conflicts. In order to identify driving conflicts in which a snowplow is in danger of rear-ending another vehicle, the other vehicle first has to be identified. Each specialty vehicle has a forward facing radar that tracks obstructions (targets) in front of the vehicle. During the testing period, as many as eleven targets were identified by the radar for a given time point, and specialty vehicle. These targets were not specifically identified from one time point to another, and therefore some tracking needed to be done in order to ascertain the behavior of each target.

To make the computing time more manageable, the targets were subset down to those targets that were of most concern at each time point. The three closest targets were identified and sorted by their distance from the specialty vehicle. Using this method target_1 was the closest target to the specialty vehicle, and target_2 was the furthest from the specialty vehicle.

Next the targets had to be tracked from one time-step to another. Each target for a given time point was compared to each of the three targets for the following time point. The position of the target at the next time point was estimated using the current position and the target_x_dot and target_y_dot variables. If the position of a future target was within five meters of the predicted position of a current target, those targets were then said to be the same target. If no future target was found, the target is said to have fallen out of range. If multiple targets meet the five-meter requirement the target closest to the predicted position is said to be the same target.

For each target, a range, range rate, and relative acceleration have to be calculated to determine the potential risk presented by the target to the specialty vehicle. The range is calculated by applying the distance formula to the x and y GPS coordinates for the target and the specialty vehicle. The distance from the front bumper of the specialty vehicle to the GPS receiver is then subtracted from the calculated distance. The range rate (rdot) calculated was the slope of the line given by the regression of the previous three range values, the current range value, and the following three range values. The relative acceleration (rddot) was calculated in a similar manner using the regression of the range rate values.

Two driving conflict identification algorithms were developed for identifying the different rear-end driving conflicts listed in Table 6-6. One is for the case in which the lead vehicle is stopped or traveling at a constant speed and the other is for the case where the lead vehicle is decelerating.

Lead Vehicle Stopped/Constant Speed:
The Lead Vehicle Stopped/Constant Speed function is:

$$\frac{(v_F - v_L)^2}{2(R - (v_F - v_L) \times t_{R,Threshold})} < a_{F,Threshold} \qquad (3)$$

where v designates a vehicle speed, R the range between the lead vehicle and the following vehicle, $t_{R,Threshold}$ the reaction time threshold, and $a_{F,Threshold}$ the following vehicle's deceleration threshold. The subscripts F and L denote following and lead vehicles, respectively. In the case where the lead vehicle is either stopped or moving at a constant/slower speed, the following vehicle will not hit the lead vehicle if it begins braking 1.5 seconds after the current time at an average deceleration of 2.44 m/s^2.

Lead Vehicle Decelerating (LVD):
The Lead Vehicle Decelerating identification algorithm is characterized by two equations. Wilson (2001a, 2001b) provides a detailed discussion of the derivation of these equations. The first equation, the **Terminal Location Equation**,

$$\frac{v_F^2}{2(v_F t_{R,Threshold} - R + \frac{v_L^2}{2a_L})} < a_{F,Threshold}, \qquad (4)$$

is applied when:

$$\frac{v_F}{a_F} \le t_{R,Threshold} + \frac{v_L}{a_L}, \qquad (5)$$

where a is deceleration. This inequality holds when the dynamic conditions of the following and lead vehicles are such that the lead vehicle will come to a stop before the following vehicle makes its closest approach to the lead vehicle. When this inequality does not hold, the following vehicle hits the lead vehicle while the lead vehicle is still moving. In this case, the dynamics are characterized by the **Minimum Separation Equation**,

$$a_L - \frac{(v_L + a_L t_{R,Threshold} - v_F)^2}{2(R + (v_L - v_F)t_{R,Threshold} + \frac{a_L t_{R,Threshold}^2}{2})} < a_{F,Threshold}. \qquad (6)$$

The same threshold values were used in this algorithm as in the "Lead Vehicle Stopped/Constant Speed." The results of this analysis are summarized in Table 6-6. The rate reported in the table is the number of conflicts per one VMT. For example, there were 1276 conflicts identified in the ambulance test road driving data with the system on where the target was decelerating and the specialty vehicle was traveling at a constant speed. This driving data represents 471 miles traveled and so the rate is 2.71 conflicts per VMT.

6.1.2.3.2 SVRD. The analysis of SVRD conflicts was restricted to unintentional roadway or lane departures. For instance a snowplow may be plowing the shoulder and have to be off the roadway to do this. Similarly the patrol car may need to do an abrupt U-turn and thus intentionally deviate from his lane. Another instance would be the patrol car pulling off the road during a traffic stop. These are not safety critical events that the IVSS is designed to aid in preventing.

SVRD conflicts were identified in the driving data when a specialty vehicle departed its lane by at least one and a half meters, and was outside of the lane for more than one second. If the specialty vehicle was outside of its lane for more than thirty seconds then it was determined that the lane departure was intentional and not a conflict. Lane departures of this kind were not considered a conflict if the turn signal in the direction of the departure was active when it occurred.

Table 6-6. Summary of Rear-End Conflicts

Type of Vehicle	Control Road	Control Master	VMT	Target Behavior											
				Constant				Decelerating				Stopped			
				Specialty Vehicle Behavior											
				Const.		Decel.		Const.		Decel.		Const.		Decel.	
				Count	Rate	Count	Rate	Count	Rate	Count	Rate	Count	Rate	Count	Rate
Ambulance	Control	Off	13	0	0.00	0	0.00	38	2.94	1	0.08	0	0.00	0	0.00
		On	4	0	0.00	0	0.00	14	3.53	0	0.00	0	0.00	0	0.00
	Test	Off	2004	220	0.11	21	0.01	4110	2.05	244	0.12	41	0.02	2	0.00
		On	471	83	0.18	1	0.00	1276	2.71	44	0.09	25	0.05	0	0.00
Patrol	Control	Off	4	6	1.55	1	0.26	16	4.13	2	0.52	7	1.81	0	0.00
		On	1	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
	Test	Off	770	121	0.16	13	0.02	1007	1.31	174	0.23	30	0.04	2	0.00
		On	205	31	0.15	3	0.01	440	2.15	24	0.12	8	0.04	1	0.00
Snowplow	Control	Off	529	1126	2.13	34	0.06	1126	2.13	12	0.02	331	0.63	0	0.00
		On	176	294	1.67	2	0.01	311	1.77	3	0.02	92	0.52	0	0.00
	Test	Off	5238	2244	0.43	94	0.02	3218	0.61	112	0.02	1633	0.31	25	0.00
		On	1970	474	0.24	18	0.01	1078	0.55	44	0.02	229	0.12	2	0.00

*RATE IS PER 1 VMT

The distance the vehicle traveled outside of the lane was determined using the width of the plow, and the width of the lane. The following assumptions were made regarding the lane width and measurement of vehicle lateral offset. Driving lanes were assumed to be twelve feet wide, and the vehicle lateral offset was assumed to be the distance from the lane center to the center of the specialty vehicle. Given these assumptions and knowing the widths of the specialty vehicles, the distance from the side of the vehicle to the lane edge can be determined.

For example, the snowplows are known to be eight feet wide. This left two feet of lane space on either side of the plow, and if the lateral offset was greater than two feet (or less than negative two feet) the plow was said to have departed the lane. The distance of the departure outside the lane was calculated as the absolute value of the vehicle lateral offset minus two feet. The results of this analysis are summarized in Table 6-7.

Table 6-7. Summary of Lane Departure Conflicts

Type of Vehicle	CONTROL ROAD	CONTROL MASTER	Visibility 100-200			Visibility 200-300			Visibility >300		
			Count	VMT	Rate	Count	VMT	Rate	Count	VMT	Rate
Ambulance	Control	Off	0	0.0		0	0.0		17	12.9	0.13
		On	0	0.0		0	0.0		7	4.0	0.18
	Test	Off	0	0.0		0	0.0		3216	2003.6	0.16
		On	0	0.0		0	0.0		653	471.0	0.14
Patrol	Control	Off	0	0.0		0	0.0		26	3.9	0.67
		On	0	0.0		0	0.0		2	1.2	0.17
	Test	Off	4	1.3	0.32	0	0.0		1374	769.1	0.18
		On	0	0.0		0	0.0		342	204.5	0.17
Snowplow	Control	Off	0	0.0		0	0.0		1657	529.3	0.31
		On	0	0.0		0	0.0		611	175.9	0.35
	Test	Off	0	1.4	0.00	18	3.6	0.50	13393	5232.9	0.26
		On	0	0.0		2	0.4	0.54	5169	1969.3	0.26

**rate is per 1 VMT*

6.1.2.3.3 Lane Change/Merge. The analysis of lane change/merge accidents must be limited to intentional departures from the lane. The specialty vehicle intends to change lanes, but comes close to an accident because another vehicle is present in the lane the specialty vehicle intends to move into. A lane change merge conflict would have been identified in the data when a driver has the turn signal activated, there is another vehicle or object in the adjacent lane/shoulder to which the driver intends to change, and the driver begins to exit his lane in that direction. The distance that the vehicle travels from its lane would be the threshold set to determine whether an event is identified as a conflict.

6.1.2.3.4 Snowplow being Rear-ended. There was no rearward-facing radar installed on the specialty vehicles. Therefore any targets approaching from the rear of the vehicle were not monitored for speed and distance. All that can be said about these types of conflicts is that no crashes of this type were observed during the FOT. Had the rearward facing radar been installed, these conflicts would be analyzed in a manner similar to the snowplow rear-ending another vehicle.

6.1.2.3.5 Next Steps for Conflict Identification. All of the results of the conflict identification algorithms presented in the previous sections were based on algorithms that need further refinement before the results could be made final. Each conflict type identified would have to be fully explored to determine whether, in fact, it was a safety critical driving situation for the specialty vehicle. This would be accomplished by exploring time plots of important dynamic variables that would help explain what is happening in each conflict identified. These variables would include velocity, acceleration, heading and lane position of the specialty vehicle plus range, relative velocity and relative acceleration of any targets detected by the radar system. If this still does not provide a clear picture of what occurred, the video data can be analyzed to determine exactly what happened. Then all conflicts that are determined not to be truly safety critical would be discarded. The other thing that needs to be investigated are the thresholds that are used for identifying conflicts. How the optimal thresholds should be chosen is discussed below, since it also depends on the estimation of the prevention ratio. It is likely that different thresholds should be used for the different specialty vehicles since they all have different capabilities.

6.1.2.4 Probability of a Crash

The conflict rates with and without the IVSS are themselves indications of how safely the drivers are operating. However, the main goal of the safety benefits analysis is to estimate the number of crashes that would be prevented. To do this, the probability of a crash must be estimated for each conflict that is identified in the FOT data.

To estimate the probability for a crash, the methodology proposed varies what happened in the conflict slightly and then determines whether these slight changes to the scenario would have resulted in a crash. The variables that are varied depend on the driving conflict being considered, but may include driver reaction time, deceleration of the specialty vehicle, and steering rate of the specialty vehicle. The idea is to investigate whether there would have been a crash if the driver had encountered the same scenario, but did not react as fast, or brake as hard. Reasonable distributions, centered at the observed value for the driving conflict, would be chosen and the variability of the distributions would be chosen so that the number of crashes under control conditions would match the historical crash rates that are available.

Using the Benefits Equation to estimate the reduction in the probability of a crash requires estimation of the prevention ratio. Estimating the prevention ratios involves estimating $P_{wo}(C \mid S_i)$ and $P_w(C \mid S_i)$. A methodology to estimate these quantities is presented below.

$P_{wo}(C \mid S_i)$ can be determined based on a combination of population crash data and FOT data by the definition of conditional probability:

$$P_{wo}(C \mid S_i) = \frac{P_{wo}(C, S_i)}{P_{wo}(S_i)}, \qquad (7)$$

where $P_{wo}(C, S_i)$ is the joint probability that a crash and driving conflict S_i occurred. $P_{wo}(C, S_i)$ can be determined from historical crash data and the methodology for estimating $P_{wo}(S_i)$ was presented in the previous section. This approach is not, however, possible for $P_w(C \mid S_i)$ as no historical data are available. An alternative approach, the conditional probability approach, is undertaken and is applied to estimation of $P_{wo}(C \mid S_i)$ and $P_w(C \mid S_i)$. Calibration of the alternative approach is carried out through matching the model-based estimate of $P_{wo}(C \mid S_i)$ with that from the value derived from historical data.

Some notation must be introduced to define the methodology used to estimate $P\,(C \mid S_i)$, the probability of a crash given that a particular driving conflict has occurred. Each driving conflict identified in the onboard driving data can be represented as

$$S_{i,j} = (X_{i,j,1}, ..., X_{i,j,k}) \tag{8}$$

where i indicates the driving conflict (i=1,…,5) and j indicates the individual conflict of type i (j=1,…,N_i). The vector $(X_{i,j,1}, ..., X_{i,j,k})$ represents the k sensor measurements taken during driving conflict i,j, which fully describe the conflict. The sensor measurements are distributed according to some unknown distribution $F(X_{i,j,1}, ..., X_{i,j,k}, \theta)$. Let

$$\delta(X_1, ..., X_k) = \{ \begin{matrix} 1 & crash \\ 0 & no \end{matrix} \tag{9}$$

be a function which determines whether an individual driving conflict results in a crash based on the values of the sensor measurements. The probability of a crash given a driving conflict is by definition, then

$$P(C \mid S_i) = \int_{\delta=1} dF(X_1, ..., X_k, \theta)\,. \tag{10}$$

This could be estimated empirically by

$$\hat{P}(C \mid S_i) = \frac{\sum_{j=1}^{\#conflicts_i} \delta(X_{i,j,1}, ..., X_{i,j,k})}{\#conflicts_i} \tag{11}$$

except that there were not enough crashes during the FOT to make this estimate sufficiently precise.

To obtain an estimate of $P\,(C \mid S_i)$, each driving conflict observed is slightly perturbed a large number of times. The reaction time, braking level and steering rate are the variables that may be perturbed according to a distribution chosen that is centered at the value observed in the data.

For each perturbation it is determined whether there would have been a crash or not and then the results are combined to obtain an estimate of $P\ (C \mid S_i)$. Development of a suitable perturbation distribution is an important aspect of this approach.

The general approach for the analytical methods has five steps:

1. Define k variables describing the driving conflict space for a given driving conflict S_i,
2. Extract from the driving conflict space parameters from each specific driving conflict found in the FOT data, denote these $S_{i,j}$,
3. Construct a function or algorithm (**analytical model**) which maps driving conflict space into probability of a crash, $P(C \mid S_{i,j})$,
4. Apply the function to each specific driving conflict $S_{i,j}$, and
5. Average the probabilities across all the $S_{i,j}$.

   The analytical model (Step 3) would differ by driving conflict.

6.1.2.4.1 Rear-end. Probability of a rear-end crash under conditions encountered in the FOT will be reduced.

Analytical methods were developed for rear-end driving conflicts, lead vehicle constant speed (LVC) and lead vehicle decelerating (LVD). At this time, these methods assume braking as the only possible avoidance maneuver. The next step was to add steering to the model.

Lead Vehicle Stopped/Constant Speed Analytical Method:

Range, range rate, reaction time, and vehicle deceleration parameters define the driving conflict space. Each of these parameters is measured for each specific driving conflict identified in the FOT data. Range is the distance between the specialty vehicle and lead vehicle at time of conflict, i.e., at the time the driving conflict is identified. Range rate is the closing rate between the following vehicle and lead vehicle at the time of conflict. Reaction time is defined as the time from time of conflict to time of avoidance maneuver (e.g., braking of the specialty vehicle or lane change of the specialty vehicle). Following vehicle deceleration is the average deceleration achieved by the specialty vehicle after the driver begins braking. Each driving conflict identified in the FOT driving data can be mapped into the space defined by these four parameters.

An example of the analytical model is presented below. A lognormal distribution was assumed for reaction time with a mean equal to the reaction time specified by the particular cell in the driving conflict space grid. Simulations were run with lognormal standard deviations between 0 and 1 second; 0.25 second was chosen. A normal distribution was assumed for following vehicle deceleration with mean equal to the following vehicle deceleration specified by the cell. The standard deviation was set at 0.15 m/s^2 (0.5 fps^2). The standard deviations would be adjusted to tune the analytical model to calibrate the estimates of $P_{wo}(C \mid S_i)$ to the values obtained from historical data.

The equation of the Lead Vehicle Stopped/Constant Speed case is:

$$\frac{(v_F - v_L)^2}{2(R - (v_F - v_L) \times t_R)} < a_F$$

where v designates a vehicle speed, R the range between the lead vehicle and the following vehicle, t_R the reaction time, and a_F the following vehicle's deceleration. The subscripts F and L denote following and lead vehicles, respectively. For the analytical model t_R and a_F are the variables that would be varied and the other inputs would be extracted from the particular driving conflict.

Figure 6-2 shows the probability of a crash for a slice across the four-dimensional driving conflict space, where range is held constant at 73 meters (240 feet), range rate at –24.4 m/s (–80 fps), and snowplow deceleration at –0.5 g (-16 fps^2). If, in a particular driving conflict in the FOT data ($S_{i,j}$), a following vehicle encountered these conditions and the driver started braking 0.5 second later, the analytical model predicts that the probability of a crash would have been approximately 40 percent. If the driver had waited 2.0 seconds, the probability increases to about 95 percent. These probabilities of a crash are high, due to the severe conditions chosen for Figure 6-2. The LVC analytical model would be applied to driving conflicts identified in the onboard driving data.

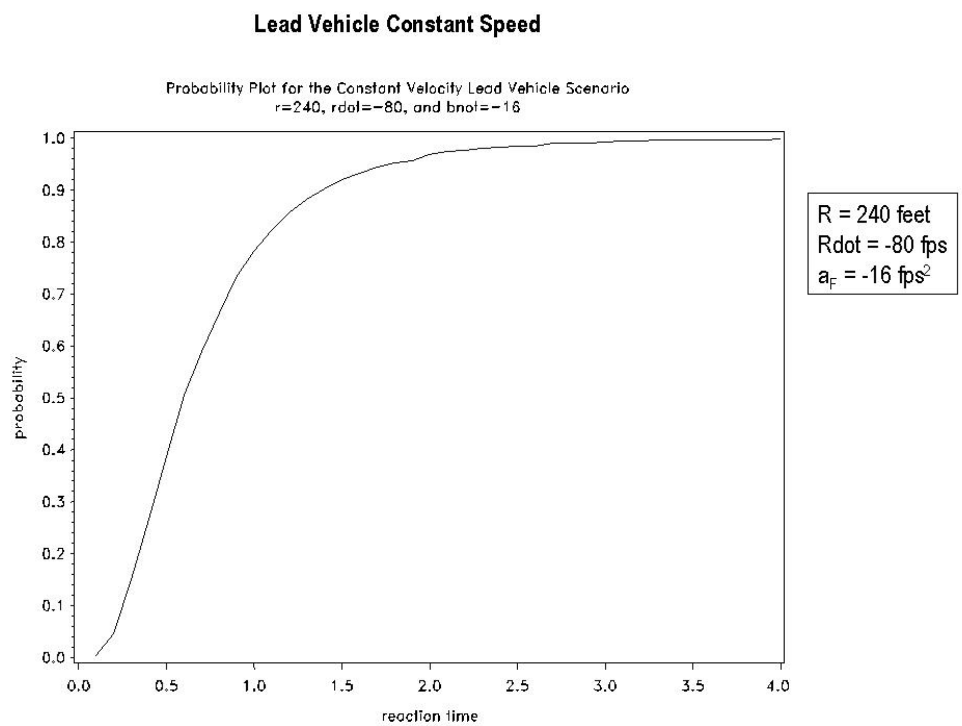


Figure 6-2. Analytical Model Developed for a Slice of the Lead Vehicle Stopped/Constant Speed Four-Dimensional Driving Conflict Space

Lead Vehicle Decelerating Analytical Method:
For this analytical method, the driving conflict space is defined by the parameters range, following vehicle speed, lead vehicle speed, lead vehicle deceleration, reaction time, and following vehicle deceleration. These parameters are measured for each specific driving conflict identified in the FOT data. Range, reaction time, and following vehicle deceleration are as described for the stopped/constant speed lead vehicle method. Following vehicle and lead vehicle speeds are the speeds of the following vehicle and lead vehicle, respectively, at the time of identification of the driving conflict. Lead vehicle deceleration is the lead vehicle's deceleration at the time the conflict is identified. Each driving conflict identified in the FOT driving data can be mapped into the space defined by these six parameters.

The Lead Vehicle Decelerating analytical model is characterized by the same two equations presented above for conflict identification. The terminal location equation,

$$\frac{v_F^2}{2(v_F t_R - R + \frac{v_L^2}{2a_L})} < a_F \ ,$$

is applied when:

$$\frac{v_F}{a_F} \le t_R + \frac{v_L}{a_L} \ ,$$

where a is deceleration. This inequality holds when the dynamic conditions of the following and lead vehicles are such that the lead vehicle would come to a stop before the following vehicle makes its closest approach to the lead vehicle. When this inequality does not hold, the following vehicle hits the lead vehicle while the lead vehicle is still moving. In this case, the dynamics are characterized by the minimum separation equation,

$$a_L - \frac{(v_L + a_L t_R - v_F)^2}{2(R + (v_L - v_F)t_R + \frac{a_L t_R^2}{2})} < a_F \ . \qquad (6)$$

The same variables, t_R and a_F, are varied for this analytical model as in the LVC model. As in the LVC analytical method, a Monte Carlo simulation was used to construct the cell probabilities. This time, the probability of a crash was calculated with the Lead Vehicle Decelerating driving conflict identification equations.

Figure 6-3 illustrates the analytical model for a slice of the six-dimensional space. The dynamic situation that triggered the driving conflict described in this plot is: the lead vehicle is 55 meters (180 feet) ahead of the following vehicle, both vehicles are traveling at 24.4 m/s (80 fps), the lead vehicle suddenly brakes hard with a 1 g (32 fps^2) deceleration, and the driver of the following vehicle responds by braking at 0.5 g (16 fps^2). As shown on Figure 6-3, if the driver of the following vehicle reacts 0.5 seconds later, the probability of a crash is about 10 percent. If he waits 2.0 seconds before he starts to brake, the probability increases to approximately 80 percent. This model would be applied to all driving conflicts identified in the FOT data.

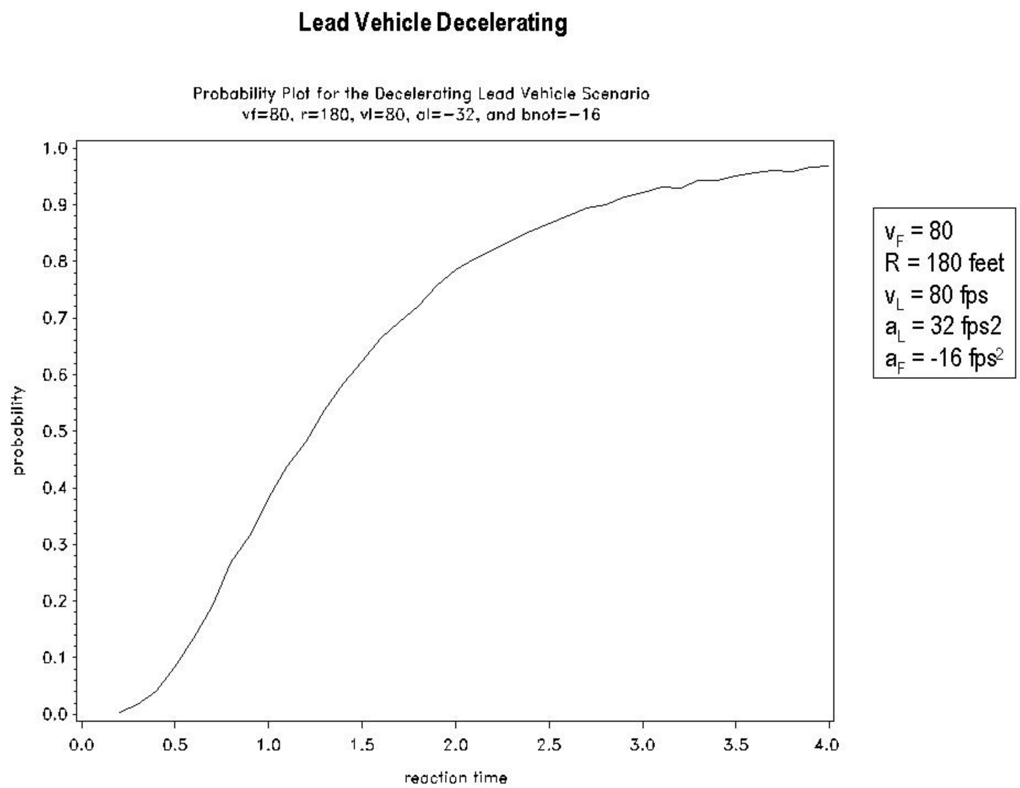


Figure 6-3. Analytical Model Developed for a Slice of the Lead Vehicle Decelerating 6-D Driving Conflict Space

6.1.2.4.2 SVRD. The final approach for estimating $P\ (C \mid S_i)$ for SVRDs was not determined. In this approach results from RORSIM would be used to determine δ. Another approach would be to base the crash probability on values determined from the particular conflict being considered. Some values that may be related to the probability of an SVRD crash are the time out of lane, speed, angle the vehicle is departing the lane, curvature of the road, steering rate or a computed distance traveled outside of the lane.

Crash probabilities would be compared for the same problem areas that were defined in the analysis of SVRD driving conflicts. The probability of a SVRD crash would be compared for specific locations with and without the driver interfaces turned on to assess whether the IVSS are successful in reducing this probability.

This location specific approach is necessary for SVRDs since there are too many confounding factors that cannot be controlled for when the locations are different (road curvature, road incline, visual clues, driver experience on road and shoulder type to name just a few). The paired comparison analysis is the only chance to control enough of this variability to be able to discern a difference in system or performance. This approach would not have been applicable to the patrol car or ambulance in the FOT because no paired comparison later would have been available.

6.1.2.4.3 Lane Change/Merge. The approach for estimating $P\,(C\,|\,S_i)$ for lane change/merge crashes was not determined. Lane change/merge conflicts can be identified in the driving data based on simple values indicating whether there is a vehicle present in an adjacent lane when the specialty vehicle indicates or begins a lane change into that lane. To develop an analytical model, however, more detailed data would be needed. Values that may be important include distance to the vehicle in the adjacent lane and rate of closure of that distance as well as velocities of both vehicles. The approach would be similar to the one used for SVRDs, but an alternative to or adaptation of RORSIM would be needed to determine δ. Comparisons of these probabilities would again be compared for driver interface on and off times.

6.1.2.4.4 Snowplow being Rear-ended. Had there been data from rearward-facing radar, the analytical methods that were used to estimate the probability of a crash for the other rear-end crashes would be used to estimate the probability of a crash in this scenario. This would depend on the exact data available from the sensors on the specialty vehicles. The difference in the two cases is that now the snowplow would only be able to react to the vehicle approaching too quickly from behind in a limited way (i.e., snowplow could accelerate or attempt to get out of the way of the approaching vehicle). The strobe light was intended to warn other vehicles so that they would be able to react sooner to the slow moving plow. Thus, this may have more of an affect on the exposure ratio than the prevention ratio. If this is the case then it is possible that the prevention ratio should be assumed to be equal to one for this crash type.

6.1.2.5 Next Steps in the Safety Benefits Analysis. The benefits equation (Equation 2) would be used to combine the results of the conflict identification algorithms and the results from the probability of a crash analytical model to estimate the benefits of the IVSS. The statistical significance of the estimated reduction in number of crashes would be assessed. The significance of the final estimate depends on the variability in the estimates of the exposure and prevention ratios. This involves a trade-off between the variances associated with the exposure ratio and prevention ratio estimates. As thresholds are set more conservatively, driving conflict intensity (probability of a driving conflict per exposure unit) can be estimated more accurately. As a greater variety of conflicts are used to estimate the prevention ratio for each driving conflict, these estimates may well become more variable. The thresholds for identifying driving conflicts in the FOT data need to be chosen to balance the variability in the estimates of these two ratios so that the overall variance of the final benefits estimate is minimized.

Besides the exposure ratio and prevention ratio, the final benefits estimate depends on quantities estimated from historical crash data. The way the conflict rates and crash probabilities are combined depends on the frequency that each conflict type precedes a crash in the historical data. One challenge faced in this FOT is the lack of a large database containing crash statistics for specialty vehicles. There is no national database available that provides the number of accidents reported involving specialty vehicles or details of these crashes, such as the National Automotive Sampling System (NASS) General Estimates System (GES) historical population crash statistics data that is available for large trucks. Instead, as many crash reports for specialty vehicles were collected from the state of Minnesota as possible. These data were analyzed to characterize the baseline crash environment faced by specialty vehicles as accurately as possible. This characterization includes the identification of the types and number of crashes that specialty vehicles trucks are involved in and determining what situations (driving conflicts) typically precede these accidents.

There is also no historical data on the number of vehicle miles traveled by snowplows. Vehicle miles traveled are used by the safety benefits estimation methodology as an exposure measure in the IVI truck FOTs. We know how many miles the specialty vehicles traveled during the FOT, but there is no historical data on vehicle miles traveled by snowplows for which the accident data are representative. A proxy for vehicle miles traveled that we planned on investigating were the annual weather conditions. The assumption is that during winters with more snow, the snowplows would drive more miles.

6.1.3 Estimate the Reduction in Crashes, Injuries, and Fatalities Nationwide if all Such Fleets are Equipped

In addition, the GES data provide information on the number of truck crashes nationally without IVSS. This information is used to estimate the number of crashes that would be avoided if the IVSS were deployed nationally. This lack of snowplow or other specialty vehicle data presents challenges to extending the results of the FOT to the national level to predict the number of crashes that could be avoided if the IVSS were deployed nationally.

The methodology discussed for addressing Objective 1A.2 permits estimation of the reduction in crash probabilities for different crash types under conditions encountered during the FOT. However, this reduction in rear-end crash probability only applies *under conditions encountered during the FOT*. Comparison of the conditions encountered during the FOT with typical driving conditions for drivers of snowplows, ambulances, and squad cars in all of Minnesota or for the entire country are required to determine to what vehicle population the reduction in crash probabilities can be extrapolated. Tests of how the FOT population of specialty vehicles are related to the other populations of specialty vehicles would determine to which populations the results of the benefits estimation can be extrapolated.

Once the target fleet to which the Objective 1A.2 benefits estimate can be applied is determined, reduction in crashes anticipated if all vehicles in the target fleet are equipped can be estimated. Based on first principles, the potential reduction in number of crashes due to full deployment of IVSS in all vehicles of the target population (e.g., all snowplows in states with similar climate to Minnesota), B, is:

$$B = [P_{wo}(C) - P_w(C)] \times E = R \times E \qquad (1)$$

where C is a crash, $P_{wo}(C)$ is the rear-end crash probability per exposure unit by the target fleet, without the IVSS, $P_w(C)$ is the matching crash probability of the same fleet equipped with the IVSS, and E is the measure of exposure for the target fleet. $P_{wo}(C)$ and E can be estimated from published or collected data, $P_w(C)$ must be estimated based on FOT data. The approach to estimation of R is outlined for Objective 1A.2.

For the results to be applicable, the road conditions and weather conditions would have to be similar to those of the FOT strip of TH-7. This would take further investigation of Minnesota and other states in the country.

Simulation models may be used to aid in extending the results from the FOT to other situations. These situations could involve different road conditions or different weather conditions. This simulation modeling would enable the results from this FOT to be extended more accurately to the state and the national, level by incorporating the general properties of the roads and weather conditions in Minnesota, and maybe the country. The simulation tools and models that would be used need to be determined.

6.1.4 Determine Whether Improved Snow Removal Impacts Public Safety

This objective is concerned with the effect of having roads cleared more quickly on the safety of other vehicles on the road or as a result of other vehicles being able to use the road. The two main focuses are quicker emergency response times because of the roads being in better condition, and fewer accidents involving other vehicles (commercial vehicles and personal vehicles). Of course having the road cleared more quickly could also result in more crashes. It may cause more cars to be out on the roads when conditions are less than ideal for driving, in which case the number of accidents may increase.

During the FOT there were no crashes of any of the IVSS-equipped specialty vehicles. Given a more typical winter with greater instances of adverse weather, even then the expected number of crashes would be very small and so we would not have been able to compare these probabilities directly. The total miles of roadway that would have been plowed quicker as a result of these technologies during the FOT was only the 45 mile section of TH- 7 and the 4 mile section of County Road 7. We would not get any driving data from private vehicles and so the methodology developed for the specialty vehicles could not be applied to them.

The only way analysis of this type can be done is by using results from previous crash data. First, the speed of the plowing would be estimated to obtain information on how much quicker the roads would be plowed and in how much better condition the roads would be. Then crash rates for different road and weather conditions would be estimated using historical crash data. The crash rate estimates could be combined with the plowing speed results to make an estimate of the safety benefits (positive or negative) that can be expected from deployment of this technology across the state of Minnesota and nationwide.

6.2 Mobility Benefits

Our approach to determining mobility benefits of IVSS deployment would be based on combining literature-derived estimates of the impacts of crashes and snow covered roads on mobility with FOT-derived estimates of crash reductions and improvements in snowplowing efficiency. Estimates of the mobility benefits would be combined with other benefits and costs in a comprehensive benefit-cost analysis (BCA). An overview of the BCA and the benefit and cost measures that are to be incorporated into the BCA are presented in Section 6.9. The following discussion addresses the analysis methods that are needed to achieve two specific objectives related to the value of the mobility benefits.

Objective 1B.1 Determine the value of the mobility benefit resulting from reduced snowplow, patrol car, and ambulance related crashes for inclusion in an overall benefit-cost analysis of the FOT.

Objective 1B.2 Determine the value of the mobility benefit resulting from increased snow removal for inclusion in an overall benefit-cost analysis of the FOT.

Mobility is measured by the net benefits to travelers or other transportation consumers from a transportation improvement. Net benefits from travel are the benefits from people's activities at their destinations, minus their travel time and other perceived costs of travel (out of pocket costs, stress, etc.) Improved snowplowing can be expected to reduce travel times and driving stress during heavy snowfall because roads are cleared and driving conditions are improved more quickly and effectively.

The main mobility benefit from this FOT, therefore, is the time and operating cost saving from traveling on better-plowed roads, which are also open more of the time during conditions of heavy snowfall. This timesaving is also likely to induce more travel during these snowy conditions, resulting in additional user mobility benefits that can be quantified using standard consumer surplus methods. These user benefits will include the costs of (otherwise) closed roads, which is an important anticipated benefit of these IVSS-equipped snowplows.

Since this FOT involved the deployment of IVSS-equipped snowplows on mostly rural and relatively outlying suburban roads, the mobility benefits would not necessarily correlate to reduced urban traffic congestion from better-plowed roads. The reason is that urban and close-in suburban roads do not have the degree of visibility problems that snow blowing across fields would produce, and mile for mile would be plowed more frequently than rural roads because of higher density traffic. We will therefore assume that the travel time savings derived from this methodology result from speed increases on better-plowed roads under relatively low volume conditions, rather than congestion reduction on high-volume urban roads. Indeed, the literature is not likely to provide information on congested speeds under different plowed conditions (i.e., speed versus volume relationships). This assumption of low volume conditions and steady state speeds by plowed condition provides a lower bound estimate of the important mobility benefit of IVI equipped plows.

Of probably less importance, but still significant, is the reduction in traffic delays to the public from the reduced numbers of accidents on the better-plowed roads. The value of these traffic delays due to accidents is generally included in the unit cost of crashes in the literature on accident costs.

6.3 Efficiency and Productivity Results

Efficiency and productivity benefits are a category of measures that help gauge whether the IVSS technology results in improvements as anticipated. To the extent that an IVSS-equipped snowplow can perform its snow-clearing tasks, or an ambulance or patrol car respond to an emergency, more quickly in adverse winter weather conditions, the measureable differences give valuable insights that can be extrapolated to a larger scale. Efficiency and productivity benefits are also important elements in the benefit-cost analysis (BCA), described under Section 6.9.

In economics, "efficiency" means maximizing total net benefits from an investment or policy. To an economist, efficiency includes all the IVSS goals that have a dollar value to society. However, engineers tend to use the term "efficiency" much more narrowly to mean more output per unit of input. Engineering efficiency, rather than economic efficiency, is well accepted as one of the major IVSS goals. Measures of achievement of the engineering efficiency goal, however, do not enter into a BCA. This is because increased output per unit of input is best measured in transportation as increased throughput or capacity (e.g., vehicles per hour, inspections per hour, inspections per person-hour). Converting this benefit to a dollar value to society falls under the productivity goal in the form of cost savings. Thus Goals 1C and 1D are combined for purposes of this plan.

Whereas "efficiency" refers to the amount of output for a given input, "productivity" means lower costs to produce a given level of output. Cost savings, as described under Objective 1D.2 below, are the most important measure of achievement of the IVSS productivity goal.

Objective 1D.1 Determine costs to deploy and maintain the IVSS technologies

The five ITS goal areas deal only with benefits (including cost savings). The cost of this Mn/DOT FOT for the purpose of this BCA consists of the one-time startup costs and the ongoing operating costs, including equipment replacement at appropriate intervals. More specifically, these snowplow IVSS startup costs include the purchase costs, one-time software development and consulting costs, and capital investments required to deploy the system initially. Examples of on-going costs are the incremental annual operating and maintenance (O&M) costs, such as consumable supplies or labor to keep the IVSS in running order. Other on-going costs would be for periodic replacement of capital equipment or components of the system.

The best available quantitative information on actual costs incurred during deployment and operation of the IVSS would be obtained from the FOT partners. If actual costs incurred were not available due to product cost sensitivity or confidentiality, then the costs would be estimated using analogous comparisons or historical data. The evaluation team would attempt to itemize these costs so that future analysts can compare the costs reported in each FOT with cost elements for related IVSS deployments in the future.

Table 6-8 summarizes the costs for the Mn/DOT FOT. The table describes the cost measures and the information sources to obtain the required costs.

Table 6-8. Cost Measures and Information Sources for Mn/DOT FOT

Cost	Cost Measure	Information Source(s)
Onetime Start-Up	Dollar value of capital equipment and software	Interviews and site visits
	Dollar value of initial driver/staff training	Interviews and site visits
	Dollar value of start-up services, installation, consultants, administration, etc.	Interviews and site visits
Ongoing	Dollar value of annual operating and maintenance (O&M)	Interviews; site visits; fleet records
	Dollar value of ongoing driver/staff training	Interviews and site visits
	Dollar value and expected service life (years) of capital equipment (used to determine recurring capital costs)	Interviews, site visits, and literature search

Objective 1D.2 Estimate the cost savings if use of the IVI technologies leads to an increase in the productivity or effectiveness of snowplow or emergency vehicle operations

Several types of cost saving may result from use of this type of IVI technology:

- More lane miles plowed per snowplow hour. The better-equipped plows may sit idle fewer hours during periods of low visibility and may plow at higher speeds with their improved tracking ability.

- Reduced driver turnover. If the better-equipped snowplows can enhance driver satisfaction and reduce stress, the agencies that deploy IVSS in snowplows and specialty vehicles may expect to see reduced rates of driver turnover and increased savings of funds normally devoted to recruitment and driver training, etc.

- Reduced infrastructure damage. More accurate snowplowing may reduce damage to guardrails and bridge abutments, etc.

- Reduced emergency response times. Faster speeds on more cleared roads may reduce the cost of emergency response vehicle operation. Also, as with the snowplows, better equipped emergency response vehicles many sit idle fewer hours during periods of low visibility and may travel at higher speeds with their improved tracking ability.

- Reduced salt or de-icing chemical use. The IVSS-equipped snowplows may impact patterns and amount of salt or de-icing chemicals used to help clear roads. The dispatching garages would have winter maintenance records that could help measure this usage.

- Fewer emergency response calls. If accidents involving the public and trucks are reduced, there would be fewer calls for, and runs of, emergency response vehicles.

6.4 Environmental Quality Benefits

The benefits to environmental quality are considered as factors in the total benefit to society from deployment of the IVSS. Fewer snowplow truck and specialty vehicle crashes would be expected to yield environmental benefits in the form of reduced fuel consumption because of reduced traffic congestion. Other possible environmental benefits may include fewer hazardous materials (HAZMAT) releases caused by crashes of vehicles carrying HAZMAT in snowy conditions. It is recognized that HAZMAT incidents, especially those resulting in releases to the environment, are especially rare events. The costs associated with reduced fuel consumption and reduced HAZMAT incidents would be factored into the benefits side of the Mn/DOT BCA.

Objective 1E.1 Determine the value of any environmental benefits that result from fewer snowplow, patrol car, and ambulance crashes, for inclusion in a benefit-cost analysis

Data for this objective would be difficult to obtain. Independent of the quality of data, the monetary value of the environmental benefits of the FOT was expected to be small at best and result from a number of rather particular impacts of the FOT. Our planned approach included assessing possible environmental benefit measures such as:

- HAZMAT crashes avoided. The environmental value of HAZMAT crashes avoided would likely be included in the documentation of a HAZMAT crash.

- Reduced air and noise pollution. Emission rates are related to speeds of plows and general traffic. Noise pollution changes are likely to be valued at negligible amounts during extreme weather conditions. Air pollution changes could be calculated using the speed information needed to calculate the mobility and cost saving benefits.

- Reduced salt use. As above, the IVSS-equipped snowplows may impact patterns and amount of salt or de-icing chemicals to help clear roads. For example, greater availability of cleared roads could perhaps increase de-icing chemical use. Salt usage, if not directly measured by the garages that dispatch the snowplows, could be determined from plowing time estimates.

- Pollution from possible changes in numbers of crashes of snowplows carrying salt or de-icing chemicals on roads cleared by IVSS-equipped snowplows. Information on snowplow crashes would be available from the safety benefits studies (see Section 6.1.2).

- Fuel consumption from higher speeds and induced auto travel. Fuel consumption may decrease with travel on better-plowed roads, even at higher speeds, but this may be offset by the effect of induced travel. In any event, the out-of-pocket cost of fuel is included in vehicle operating costs.

6.5 Driver Acceptance and Human Factors

When it was determined that a complete safety benefits assessment was not possible due to the scarcity of data, USDOT directed that Battelle generate a white paper addressing general observations on the drivers' willingness to accept the specialty vehicle IVSS. The detailed data that describe responses from each of two Internet driver surveys and the two in-person interviews, along with the findings of the analysis of those data, are presented in *Mn/DOT Driver Acceptance: IVI FOT Evaluation Report*, Battelle, 2003. This section summarizes the approach used in this analysis.

Driver Acceptance and Human Factors Objectives

Battelle's evaluation plan outlined five goal areas for the evaluation of IVSS: (1) Document benefits, (2) Assess user acceptance and human factors, (3) Assess system performance, (4) Assess product maturity for deployment, and (5) Address institutional and legal issues that might impact deployment. Goal area 2 defined four human factors objectives that were to be addressed through questions posed in surveys or in-person interviews, analysis of selected driving data, or through the ergonomic analysis of the on-board systems. These objectives focused on perception of usability, training requirements, job satisfaction, and workload, driving behavior, and product quality and maturity.

In addition, these objectives helped understand if and how human factors played a role in the eventual acceptance and deployment of the systems. For each of the four Goal Area 2 objectives, we defined a series of hypotheses to be addressed through driver surveys, interviews, or the ergonomic assessment. The four objectives associated with Goal Area 2 and the accompanying hypotheses tested in the FOT are detailed below. In addition to the following four objectives, background and baseline information were gathered to provide some historical information about the drivers' experience and to allow an understanding of what the drivers' thoughts and perceptions of the system were before they had any contact with the technologies.

Objective 2.1: Determine the vehicle operator perceptions of the usability of the IVI technologies

This objective focused on how IVSS were used and understood by the drivers, in particular the drivers' understanding of signals and information; perceptions of consistency and robustness of signals; how the information was integrated and presented to the driver; and the ease of learning, use and control.

Objective 2.2: Determine perceived effects of the IVI technologies on operator training requirements, job satisfaction, stress, workload, and fatigue.

This objective focused on how the IVSS affected the driving environment. Of particular interest were the effects of false alarms and the impacts on driver workload.

Objective 2.3: Determine the perceived effects of IVI technologies on the driver in terms of behavior risk modification and changes in driver vigilance.

While one of the objectives under Goal Area 1A (safety benefits) addressed whether or not drivers modified their driving behavior (and the degree to which modified behavior is safe), this objective was concerned with learning why drivers modify their driving behavior.

Objective 2.4: Determine perceptions of product quality, value, and maturity and establish customer willingness to pay.

Information on the perceived quality, value, and maturity of the IVSS from the perspective of the users (drivers, mechanics, and other fleet personnel) was obtained.

Overview of Approach

Evaluation methods included in-person interviews with drivers and their supervisors and Internet-based surveys of the drivers (see Appendices C and D). These were used to gather baseline information before the drivers had significant experience with the new IVSS technologies and later after they had experience with the technologies under the winter conditions for which they were designed.

An objective of the initial baseline Internet survey (18 drivers) was to assess driver expectations for the use of the safety technologies and to ask drivers about their experiences with early versions of the technologies. It was known at the outset that there had been significant technical problems with the performance of the GPS in particular that resulted in incorrect or unusable displays of roadway information that could not be corrected prior to the start of the FOT. The final Internet survey (13 drivers[3]) sought to identify changes in driver perceptions based on their experiences with the IVSS. The baseline driver interviews (12 drivers[3]) and final interviews (12 drivers[3]) supplement the objective data collected in the surveys with a more open-ended, subjective discussion of expectations, experiences, and issues with the technologies. In addition to the data collected from the drivers, baseline and final interviews were conducted with selected supervisors (4 in the first interview and 3 in the second interview) in order to obtain their perspective on these safety systems. Findings from all these data are integrated in this report.[4]

Data collected at the initial and final time points allow for descriptive analysis of data on driver expectations, perceptions, and experiences at those time points, and also allow for a comparative assessment of any changes in responses and perceptions over the time period covered by this

[3] Not all of the original 18 drivers were available for either of the interviews or the final Internet survey.
[4] Information that could reveal a driver's identity has been removed from this report, as all drivers were assured of confidentiality in the surveys and interviews.

evaluation. Data from the same or similar questions asked at both points in time are analyzed to determine any changes in perception over time. Changes in perceptions are examined for groups of drivers (group averages for example) and at the individual level for the ten drivers who participated in both the first and second Internet surveys (to examine any changes in responses by the same person at both time points). In addition, where possible, comparisons between the survey responses and the objective systems data are provided as a way to discern how accurately drivers monitor their behavior and the accuracy of their perceptions of the system's performance.

This evaluation was conducted in parallel with a similar but independent evaluation conducted by the University of Minnesota (2002). Evaluators from both teams met periodically to discuss and coordinate plans for surveying and interviewing drivers, both to enhance the quality and comparability of the two evaluations, and to minimize the burden on the drivers to meet with the evaluators and respond to questions.

Conceptual Model

Figure 6-4 presents a conceptual model that illustrates sets of factors expected to influence how specialty vehicle drivers might be affected by the IVSS technologies. These factors were examined in the driver and supervisor surveys and interviews, and they include driver background, driver expectations about the IVSS, external conditions affecting the use of IVSS, and how these interact to influence driver perceptions and experiences with the IVSS. Essentially, the key areas of Baseline Perspective and Driver Expectations (obtained prior to operational experience with the IVSS), and Driver Experience with the IVSS, Attitudes/Perceptions/Behaviors/Values, and Conditions of Use (obtained during or after operations with the IVSS, influence each other to a large degree and together help define the expected, measureable outcomes.

The first step (Baseline Perspective) is to take account of pre-existing experience and perspectives that can directly impact the outcomes of interest, as well as influence these outcomes through their indirect effects on driver expectations about the new technologies, their experiences and reactions while using the technologies, and their attitudes towards the technologies' benefits. These baseline perspectives are drawn from drivers' training, driving experience, level of comfort with any kind of new technology, and the extent to which their organization and fellow drivers support or criticize the technologies.

Taken together, these conditions and factors from the Baseline Perspective directly affect the likelihood there would be driver trust that the technologies even have the *potential* to offer benefits. Another key set of conditions affecting the outcomes include whether the technologies work as they are supposed to (Driver Experience Using IVI Technologies) and whether the external driving conditions and environment are conducive to a successful outcome (Conditions of Use). Finally, Driver Experience is affected by Attitudes/Perceptions/Behaviors/Values. In the case of this evaluation, we know that some aspects of the technologies were not functioning correctly, or at all, and we also know that the needed low visibility weather conditions that were critical for an adequate test of the intended use of the technologies were almost non-existent during the evaluation period. In spite of these problems, most of the drivers were willing to put the technologies to the test where they could, and they were quite willing to share their experiences and opinions with the independent evaluation team.

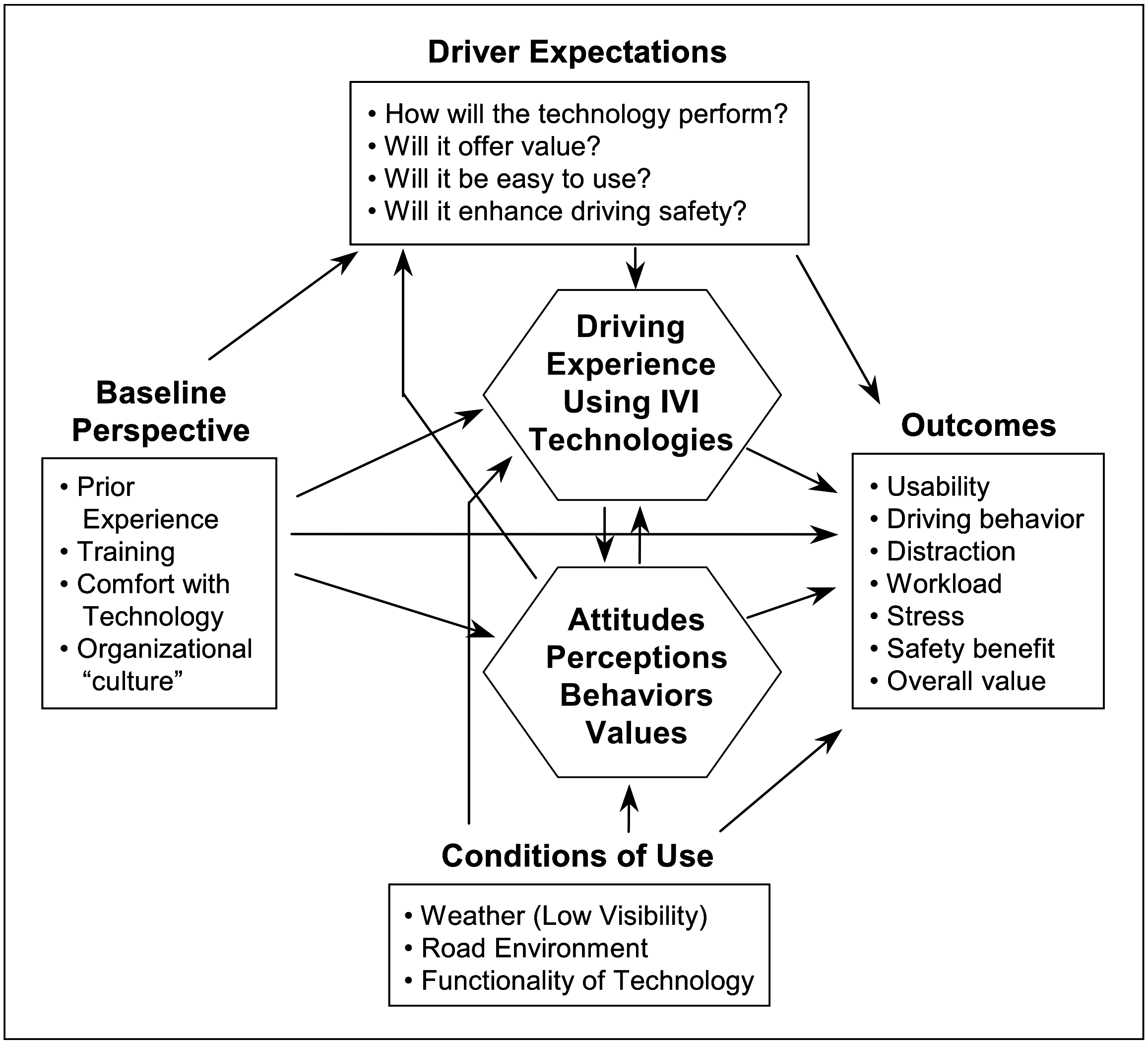


Figure 6-4. Factors Affecting Driver Acceptance of IVSS Technology

6.6 System Performance

In the evaluation plan, the 3 evaluation objectives related to system performance were:

Objective 3.1 Characterize the expected performance and functionality of the IVI system

Objective 3.2 Assess the capability of system components

Objective 3.3 Determine the expected reliability and maintainability of the IVI system

The approach to evaluating the first two objectives is discussed below. For the third objective – determining the expected reliability and maintainability of the IVI system – had there been more snow and low visibility conditions, we would have examined maintenance data, dispatch logs, and downtime indicators in addition to what we gathered from driving data, surveys and interviews.

System Performance, Functionality, and Capability

Given the expected snowfall and low-visibility conditions, we would have relied heavily on analyses of onboard driving data to understand the expected system performance, functionality and the capability of system components (in order to meet objectives 1 and 2 above). Section 5.1 presented previously describes the onboard driving data that were collected during the FOT. However, since those data were of insufficient quantity, Battelle's approach for those objectives during the FOT primarily had to rely on the University of Minnesota's FOT Validation Report.

Since the FOT didn't proceed as expected with regard to snow and low-visibility conditions, we were prepared to implement our proposed research options explained in Appendix F. These options were test plans for supplemental/alternative evaluation studies that we developed in the event of insufficient low-visibility weather conditions during the FOT. They included both system performance and human factors considerations. They were intended to mitigate evaluation constraints brought about by the lack of adverse weather and would have involved substantial collaboration with the Mn/DOT Partners.

For example, two of the options involved controlled tests to (1) evaluate system performance, and (2) evaluate drivers' ability to rely on the vision enhancement system. Battelle submitted these options in February 2002 but USDOT subsequently made decisions with regard to the FOT that did not incorporate these proposed options.

There were no crashes involving the specialty vehicles during the FOT. Given the short time span and limited vehicle miles traveled during this FOT, few crashes were anticipated. If a crash had occurred, the onboard driving data would have been supplemented with police reports and internal Mn/DOT reports. The typical crash information extracted from police reports includes vehicle speed, road condition, roadway alignment, and crash circumstances. Crash data, if significant in occurrence, could serve a number of purposes. First and foremost, the data provide information pertaining to the circumstances surrounding a crash. The combination of parameters collected from the onboard snowplow data can be used as inputs to model simulation for performance evaluations. The driver's reaction to the IVSS (if activated) could be compared to reactions of drivers in non-crash situations (if available).

6.7 Maturity for Deployment

Tracking the maturity of IVSS product development and making these products ready for implementation and subsequent deployment is essential to demonstrating the viability of the product. Traditionally, science and technology programs refer to "research," "development," and "demonstration" as maturity stages. The first step in assessing product development is determining which of the three maturity stages apply. Research applies the potential solution to problems. Development brings the solution to bear on a specific problem and generates the technical, cost, and engineering data required for demonstration. Demonstration shows the performance of a solution, its complete implementation cost, and reveals any scale-up issues that may exist. In principle, completion of a demonstration provides a potential user with enough information to decide whether or not to deploy the solution.

The criteria necessary to satisfy that the IVSS technology has matured to the demonstration and deployment stages include the following:

1. **User Need**: Is the need documented?
2. **Technical Merit**: Is the product technically sound?
3. **End User Involvement**: Is there strong end user support for deployment?
4. **Cost Effectiveness**: Would money be saved relative to baseline operations?
5. **Risk Tolerability**: Are there any risk issues that affect deployment?
6. **Stakeholder Acceptance**: Are the stakeholder issues identified and mitigated?
7. **Commercial Viability**: Are vendors available to provide the technology?

In order to assess the likelihood that the IVI technologies would achieve the above criteria, the following would address the action items to collect the information necessary for maturity assessment.

Objective 4.1 Estimate production system purchase price, installation (after market) costs, and maintenance costs.

The purchase, installation, and maintenance costs related to the IVSS components as tested in an FOT are important to document. However, it would be equally important to project these costs during mass production and deployment. Key measures would include actual costs as reported by the FOT partners and vendors and estimated costs projected by experts in the area of new technology deployment.

Once the product has demonstrated significant end-user demand, the next expectation is that the product meets the cost/benefit requirement to be economically viable. The specific hypothesis to be answered is:

Hypothesis 4.1-1 The cost of purchasing, installing, and maintaining IVSS technologies is reasonable for organizations that operate snowplows.

Many products may be technically sound and applicable to improving safety and yet may be economically unacceptable. Ideally, life-cycle costs should be the guiding data. The above seven criteria that prove the technology is ready for deployment all have some impact on life-cycle cost.

The following work activities provide the methodology for testing the hypothesis:

- Based on the prototype development, we would attempt to obtain purchase records for the fully engineered system from the vendor. Typically these costs far exceed mass production costs. If purchase records are unavailable, we would prepare a preliminary cost estimate based on specifications.

- We would obtain input from the cost-benefit study in order to quantify cost effectiveness and document user need.

- We would survey the component vendor, product developer and fleet maintenance personnel to estimate product design life based on a specified operating environment.

- We would check with the developing designer and manufacturer to ensure that the system is properly sized, final production specifications, engineering drawings, and calculations are complete and peer reviewed. This would demonstrate technical merit.

- We would identify the institutional and legal risks of deployment and estimate their potential cost. This would establish a risk tolerability limit as a function of cost.

- During operations, we would examine vehicle operations and maintenance (O&M) records to assist in estimating costs and savings associated with O&M of the IVSS. This would document cost effectiveness.

- We would identify design interface requirements between the system and the vehicle, and survey the designer for compatibility issues.

- Based on the design interface requirements, we would check with the fleet operator to qualify any costs related to modification of the snowplow.

- If modifications were made, we would document costs associated with a regularly scheduled maintenance checklist for inspection or servicing.

Objective 4.2 Assess infrastructure investment needs.

Certain types of safety systems (such as the lateral guidance that used magnetic tape) demand interaction with the infrastructure, requiring an investment in the infrastructure. Some of the IVSS components tested are contained entirely within the vehicle and should require little or no assistance from the infrastructure. We may consider whether the IVSS operation could be enhanced by infrastructure improvements. The specific hypotheses to be tested are as follows:

Hypothesis 4.2-1 The IVSS require little or no modification to the infrastructure for effective operation.

Hypothesis 4.2-2 Infrastructure investments needed to operate and maintain the IVSS are minimal.

The following work activities provide the methodology for testing the hypotheses:

- We would perform an engineering analysis to determine if changes to the infrastructure could enhance the IVSS used in the FOT.

- If any changes are identified, involved stakeholders would be interviewed to determine feasibility and any issues.

Objective 4.3 Determine availability of state-of-the-art, low-cost manufacturing capabilities.

Special manufacturing capabilities might be needed to mass-produce selected IVSS components at competitive costs. Assessments of the manufacturing capabilities by the FOT participants, as well as independent technology development experts, are needed. There are several manufacturers today that specialize in this type of technology transfer application. The specific hypothesis to be tested is:

Hypothesis 4.3-1 Low-cost, state-of-the-art capabilities exist and are available to mass-produce the IVSS.

The following work activities provide the methodology for proving the hypothesis and establishing commercial viability of new components as appropriate:

- Interview the American Trucking Association (ATA) and perform an Internet/literature search to identify potential manufacturing sources.

- Interview potential suppliers and utilize findings to assess if these vendors are capable of mass-producing the IVSS technology.

- Interview equipment manufacturers and determine if installing and manufacturing the IVSS components has proprietary or patent protection.

Objective 4.4 Assess the need for modifications to ITS standards to facilitate deployment.

The IVSS components as a total system do not operate without assistance from infrastructure. We would not anticipate modifications to infrastructure-related ITS standards would be required, and no in-vehicle standards appear to be applicable. The specific hypothesis to be tested is:

Hypothesis 4.4-1 The information needs of the system can be handled by existing standards.

The following work activities provide the methodology for proving the hypothesis:

- Analyze the interfaces needed for other systems to identify applicable standards

- Review the applicability and adequacy of DOT ITS standards documents under development, and published or approved standards to confirm that the hypothesis is valid.

- Interview members of the Council of Standards Organization (CSO) committees for additional insight into proposed or pending standards.

Objective 4.5 Determine whether the system is suitable for widespread deployment.

This objective would be the most substantially evaluated one under this goal area. Achieving nationwide benefits would require that the system be deployed in a variety of specialty vehicle types. Most of the evaluation analysis would concern the systems as they were used during the FOT, but this objective is to determine whether the systems are sufficiently mature to be deployed in more widespread operations. Battelle would contact some other transportation organizations with preliminary results of this evaluation to learn their opinions of the IVSS.

The specific hypotheses tested are:

Hypothesis 4.5-1 Are the IVI technologies mature enough to be used in adverse conditions on other snowplows, patrol cars, and ambulances in other areas that are geographically similar to the FOT?

Hypothesis 4.5-2 Are the IVI technologies capable of being used on other snowplows, patrol cars, and ambulances in arreas that are not geographically similar to the FOT?

The following work activities provide the methodology for proving these hypotheses:

- Interview drivers and maintenance personnel and determine the extent of system modifications, if any, necessary to accommodate the full range of field test conditions anticipated.
- Conduct an angineering and human factors analysis to assess the effects that differences in terrain have on the IVSS.
- Contact other specialty vehicle fleet operators and interview them to determine applicability of IVSS to their fleet operations.

6.8 Institutional and Legal Issues

Effectively meeting the established performance and benefit goals may not be sufficient to ensure the success of an FOT. Institutional and legal issues can impact the project negatively, resulting in reduced benefits or outright failure. On the other hand, a well-organized and informed institutional and legal environment can be a positive asset that leads to even greater support for and benefits from the project. The following questions characterize the important institutional issues that would be considered:

- Are the right organizations and political jurisdictions aware of the project, exchanging information about it as needed, and supportive of it? Consider both the private and public sectors, legislative bodies, unions, members of the general public, and other possible organizational stakeholders.
- Are current channels of communication and data sharing among these organizations and jurisdictions adequate? Are new ways to exchange information needed?

- Is it clear who needs to participate in making decisions that affect the project, and are those persons satisfied with their level of involvement?

- Are current organizational procedures in place and adequate to support the project? This may include such elements as: procurement, staffing, partnering agreements, data ownership and sharing.

- Are there any issues with regard to intellectual property rights that have not been adequately addressed?

- Are the project's stakeholders identified and supportive?

- Have the full range of potential institutional issues and concerns been identified and characterized sufficiently to allow them to be avoided or mitigated?

- Where potential or actual institutional issues are identified, are strategies identified for avoiding or mitigating the impacts?

The legal issues deal primarily with the regulatory issues and liability risks associated with project deployment and how they can best be anticipated, and prevented or mitigated. Legal issues can arise in conjunction with such aspects as

- product failures,
- driver distractions,
- loss of vehicle control,
- property damage, and
- tort liability.

Institutional and legal issues cover a broad area, and require substantial work to assess them. Considering the potential scope, the evaluation approach described in this section would be prioritized, after the initial review of the potential issues and concerns, to focus on those aspects of greatest perceived importance and potential consequence for project success.

Objective 5.1 Identify and Determine the Potential Impacts of Institutional and Legal Issues.

The methodological approach to addressing institutional and legal issues would be to identify important issues that could affect the success of the IVI program in general and the deployment of the specific IVI technologies evaluated in particular. Identification of institutional issues requires an understanding of the relevant organizations, jurisdictions, and individuals as stakeholders in the outcome of this deployment, the adequacy of organizational procedures for managing the project components, and the perception of any potential problems due to the deployments that would need to be addressed and managed. Identification of legal issues involves an examination of regulatory issues and liability risks that apply to the IVI program and the technologies being deployed. For both institutional and legal issues identified in this analysis, strategies for mitigating or avoiding problems would be identified as outlined below.

Effectively meeting the established performance and benefit goals may not be sufficient to ensure the success of the Mn/DOT IVI technologies into other projects. Institutional and legal issues can impact the project negatively, resulting in reduced benefits or outright failure. For example, a stakeholder inadvertently left out of the process or ignored can become an intractable opponent of an otherwise successful and useful IVSS implementation. On the other hand, a well-organized and informed institutional and legal environment can be a positive asset that leads to even greater support for and benefits from the project.

The following outlines the work that was planned to assess institutional and legal issues for the Mn/DOT specialty vehicle projects

Institutional Issues

The approach to assessing institutional and legal issues would focus on those aspects of greatest perceived importance and potential consequence for project success. The following specific tasks would be undertaken to meet this objective:

1. The organizations that have an interest or stake in this program would be identified, along with knowledgeable individuals who could discuss the relevant institutional aspects of each organization with regard to this program. A list of public and private organizations and agencies, along with contact persons, would be developed. This would include state organizations connected with the specialty vehicles, agencies with regulatory authority over the operations of this project, and others that may be identified as having an interest in the outcome of this FOT or that are judged to be in a position to influence the success of the project.

2. The roles, responsibilities, and other activities of these organizations that relate to the project would be summarized.

3. Individual stakeholders and individuals with domain knowledge would be interviewed to understand how they normally address institutional and legal issues, and to identify any particular issues and concerns that could have a bearing on the success of deploying these technologies.

4. Strategies for avoiding or mitigating institutional issues that might adversely impact deployment would be identified.

5. Opportunities to capitalize on institutional strengths would be identified.

Telephone interviews would be conducted with spokespersons for the Mn/DOT Office of Advanced Transportation Systems, University of Minnesota's Intelligent Vehicle Laboratory, 3M Corporation's ITS Project Office, Altra Technologies, Inc., the Commercial Vehicle Safety Alliance (CVSA), American Trucking Association (ATA), the insurance industry, unions, and legal contacts, to explore these stakeholders' perspectives on the institutional and legal issues that pertain to this FOT. Additional contacts would be solicited from these initial contacts to assure comprehensive coverage of the issues.

The following questions characterize the important institutional issues that may be discussed with these contacts:

- How does each of the stakeholder organizations take account of institutional and legal issues that may be relevant from their point of view with regard to new safety technologies on specialty vehicles?
- What institutional involvement does each of the stakeholder organizations have with the core IVSS technologies (collision avoidance and lane keeping)?
- Are all the organizations that have an interest in being involved in this program properly included, and are they satisfied with their level of participation and ability to influence decisions?
- Are information and data flowing through appropriate channels, and are the stakeholders satisfied with the level and timeliness of the information they are provided? Furthermore, do they feel their concerns are being heard and acknowledged?
- Are stakeholders who desire to be part of, or to influence, the decision processes satisfied with their roles in the program?
- Are various institutional elements within the program functioning smoothly? These might include oversight, regulation, staffing, training, procurement, maintenance, partnering agreements, data ownership and sharing.
- How are managers, insurers, drivers, regulators, and others reacting to the IVSS technologies?
- Where institutional issues have been identified, are they being adequately addressed and managed? Can any adverse consequences be effectively mitigated?

Strategies for avoiding institutional problems, or mitigating those that arise, include the following steps:

1. Some institutional issues or problems can be avoided simply by understanding the current institutional conditions, anticipating where problems could potentially arise, taking the appropriate steps and making the needed adjustments to be sure the problem doesn't have a chance to materialize. A process for identifying and anticipating institutional issues has been described above. Once identified as a potential problem, the preferred approach is to take those actions that would avoid altogether the issue ever materializing.

2. Institutional issues often arise because stakeholders and other institutional or organizational entities simply don't know or don't understand what the project is all about. Enhancing awareness and understanding can go a long way to avoiding and mitigating institutional issues and concerns. The following kinds of strategies would be suggested, as appropriate to the particular issue:

a. Build awareness with educational materials, such as:
    - Fact sheets and brochures
    - Internet sites
    - Newsletters and magazine articles
    - Public service advertisements
    - Presentations at stakeholder meetings and similar forums
    - Town and neighborhood meetings
    - Papers at professional conference
    - Interviews with various media

b. Strengthen organizational interactions by identifying appropriate individuals to be included in key decision processes, thereby building buy-in to the program. This could be done by including institutional representatives on committees or task forces or by establishing special working groups with membership from various institutions and program management.

c. Establish training programs to enhance critical skills as may be needed in selected organizations for successful operation and maintenance of these new systems and technologies.

3. A mitigation strategy may be to selectively control such institutional liabilities by avoiding those aspects of the program that are found to be particularly objectionable. Alternatively, it may be prudent or necessary to change some aspect of the program to make it more acceptable to various institutional entities.

Legal Issues

Legal issues deal primarily with the regulatory issues and liability risks associated with project deployment and how they can best be anticipated, addressed or mitigated. Legal issues can arise in conjunction with such aspects as product failures, driver distractions, loss of vehicle control, property damage, and tort liability. There may also be concerns by employees regarding "privacy" or "supervision." Legal liability risk, as a concern that may constrain or delay deployment of safety-enhancing technology, is that the cost of defending against law suits and payments of awards or settlements associated therewith would outweigh the benefit of the technology from the perspective of the manufacturer who offers the technology or the fleet operator who purchases it. Such an outcome is unfortunate from a public policy perspective if the savings in lives, injuries and property from deployment of the technology are substantially greater than the losses that may be suffered from its failure or misuse.

Manufacturers and operators face "product liability" exposure, where it is not necessary to prove negligence or fault, but rather only that the product was placed into the "stream of commerce" and that it contributed to the cause of the injury. Scenarios of potential liability risk include the following:

- The device fails to operate as designed, and the failure is deemed to be a cause of the injury.

- The operator relies on the device in a way for which it was not designed but for which a jury determines, could have and should have been foreseen.

- Plaintiffs' attorneys seeking "deep pockets" may seek to attribute crashes or incidents to the technology whether a causal link exists or not.

- If the device proves over time to be an effective means of reducing crashes or other incidents, then creative lawyers may charge negligence on the part of manufacturers or fleet operators who fail to equip their vehicles with the device.

Insurance companies over time would make an assessment as to the increase or decrease of exposure to risk of claims associated with the technology. If companies are satisfied that use of the technology would reduce the likelihood of accident injury and damage, they may reduce premiums for operators.

Manufacturers are concerned that as safety-related technologies are developed, federal regulatory agencies may mandate their use; however, complying with such a mandate and associated standards, in the event of system failure or misuse, increases the exposure of the manufacturer to suit.
Collaboration with government agencies or within industries may be constrained by the desire of the manufacturer to protect intellectual property and/or secure a competitive advantage in the marketplace with its development and marketing of technology.

The following specific tasks may be undertaken to identify legal issues, impacts and mitigation strategies:

1. Identify program consistency or inconsistency with the laws and regulations that apply to the IVI program and the technologies being deployed, and across the various jurisdictions in which the program would be implemented.

2. Discuss stakeholder perspectives on potential legal issues and risks with FOT team members and project partners, product vendors, and legal staffs of relevant agencies and organizations.

3. Prepare a list of legal and liability issues and concerns, and prioritize them for attention by legal experts.

4. Identify strategies for avoiding or mitigating these potential legal and liability risks.

Mitigation strategies may include the following:

- Emphasis on human factors research to assess how the vehicle operator uses the technology and potential for misuse. Take potential for misuse into effect in design of user interface.

- Care in development of instructions for use and training procedures to assure proper use and proper maintenance.

- Involvement with legal counsel responsible for defending product liability suits as technology is developed to assure documentation of due diligence.

- Collaboration with insurance companies and regulating agencies as the device is developed and tested to demonstrate its effectiveness and to assure that the process of deployment and regulatory oversight proceeds in a timely and effective way.

- Determination of policies regarding data collection, storage and use in consultation with regulators, risk managers, and employee representatives.

6.9 Benefit-Cost Analysis

Benefit-cost analysis is the means by which the net benefits of transportation improvements are aggregated and quantified so that decision makers can develop policies and guidelines for investments and deployments based on results of FOTs. Different types of data are required to expand the benefits nationally, but all the benefits arise from the expectation that the specially equipped snowplows can clear roads faster, safer, more accurately, and under more adverse weather conditions than conventional snowplows. This should result in fewer crashes involving snowplows, and improved driving conditions for the public on roads that are open more of the time, are safer to drive on, and which allow driving at somewhat higher speeds during periods of heavy snow.

The safety benefits estimates would be among the factors applied to benefit-cost estimates for Minnesota. If feasible, these estimates would be expanded to a national basis, using some rational basis for projection. All the benefits and costs would be expanded to reflect the economic benefit, or net worth of adopting the FOT improvements nationally. National markets are needed for the viability of the manufacture and deployment of the IVI technologies being evaluated. Benefit-cost analysis is the means by which the net benefits of transportation improvements are aggregated and quantified so that decisionmakers can develop policies and guidelines for investments and deployments based on results of FOTs.

The purpose of the benefit-cost analysis (BCA) is to sum up and compare all available monetary elements derived from the other measures in the evaluation (safety, crash avoidance, deployment cost, operating cost, mobility cost to society, etc.). The BCA compares all of a project's benefits to society with all of the project's costs to society over the life of the project or system being analyzed. A benefit-cost ratio (BCR) greater than 1 indicates that the systems are worthwhile (i.e., that their lifetime benefits are worth more than their costs). A BCR less than 1, by contrast, indicates that society would be better off by maintaining the status quo, and not deploying the subject systems. The discussion below describes the approach we would have taken to this coordinated BCA. The specific hypothesis to be tested in a BCA is that the total cost to society of developing, deploying, and maintaining the IVSS is less than the combined value of all the benefits.

The evaluation of the Mn/DOT IVI FOT was more complicated than those of the three related, commercial truck FOTs (Freightliner, Volvo, and Mack), because the Mn/DOT innovation potentially affected driving conditions for the general public. For Mn/DOT, careful records would be required to document

- The increased frequency of dispatching IVI-equipped snowplows in adverse weather conditions
- The increased lengths of roads able to be plowed with the IVSS-equipped snowplows, versus the "old" unequipped plows
- The frequency and durations of the weather conditions under which the new plows provide benefits
- The frequency of these weather conditions during a typical winter in the FOT area.

Changes in numbers of accidents involving the new snowplows estimated/observed in the FOT would be expanded using these data. Reductions in accidents involving the motoring public and travel time savings to the public are likely to be one of the two economic benefits of the greatest value to society. Reductions in accidents would be estimated using accident rates by plowed road conditions obtained from various researchers, including important work carried out at the Iowa State University (e.g., studies by Nixon and Knapp[5]). This benefit would be expanded nationally using the increased times and lengths of road able to be plowed with the IVI-equipped plows in states in the various categories of winter storm severity. In this expansion, the VMT data by state and road type would need to be adjusted in three ways using:

- Seasonality and time of day factors by type of road using commonly available traffic engineering data
- Reductions in VMT (volumes) during severe winter storms, either observed by state highway departments, or from surveys of travel behavior during snow and ice conditions (e.g., Public Sector Consultants[6])
- Increases in travel induced from the mobility/travel time benefit described below.

The other major economic benefit to society would be the value of the improved mobility to the public (including trucks) during the increased times and on the lengths of roads able to be plowed (only) with the IVSS-equipped snowplows. The applicable benefit measure would be

[5] Knapp, K., Kroeger, D., and Giese, K. (2000). Mobility and Safety Impacts of Winter Storm Events in a Freeway Environment, final report prepared by Iowa State University (Ames, Iowa) for Iowa DOT, Project TR-426 (February 2000); and Nixon, Wilfred (unpublished). Winter Transportation Problems: Identifying Strategies to Improve Safety and Reduce Economic Burdens, project by Iowa State University (Ames, Iowa) for Iowa Department of Transportation, Midwest Transportation Center (1991 to 1994).

[6] Public Sector Consultants, Inc. (1993), The Use of Selected Deicing Materials on Michigan Roads: Environmental and Economic Impacts, prepared for Michigan DOT, Appendix A, Survey of Motorists, December 1993.

travel time savings, and in some instances, lengthy time savings from fewer road closures. Travel speeds versus plowed conditions would have been observed during the FOT. Data on this relationship are also available from various researchers (e.g., Iowa State University) and from various AASHTO and TRB conference papers on Snow and Ice Control (e.g., Roanoke and Juneau[7]). Again, the national expansion would use the VMT and lengths of road able to be plowed (only) with the IVSS-equipped plows in states in the various categories of winter storm severity. The benefits from induced travel due to the improved travel times—and from fewer road closures—would have been expanded in the same manner.

The key to expanding the benefits nationally would be to determine the highway mileage plowed, and the vehicle miles traveled (VMT) by the public during the weather conditions under which the new plows provided benefits. Excellent data on snowfall amounts and duration by states and smaller areas (including the FOT area) are available from the National Climatic Data Center (lwf.ncdc.noaa.gov). We would have extended the methodology of the Strategic Highway Research Program to determine the highway mileage and VMT in various categories of winter storm severity categories using FHWA Highway Statistics data on mileages and VMT by state and type of road (FHWA 1997). To expand the benefits beyond the FOT, data would be required on the weather condition distribution for the states and regions to which the Mn/DOT results are being expanded. Finally, estimates would be needed of traffic volumes nationally, which are likely to be traveling during the weather conditions under which the new plows provide benefits.

With regard to changes in mobility patterns, the calculation and expansion of the benefits from accidents avoided need to account not only for “stay-at-home drivers” during winter storms, but for travel (VMT) induced by the improved plowing. It is speculated that, if IVSS-equipped snowplows clear impassible roads more quickly and efficiently, then, during and following a snow event, drivers who might otherwise have stayed in would be induced to travel. This kind of induced travel in effect increases the amount of driving during a given time. The induced travel could help the economics of the IVSS (by increasing the productivity and efficiency of workers and commercial travelers), or it might increase the risk of crashes during a given period when, prior to IVSS deployment, few vehicles would have been on the road.

The last likely major category of economic benefits would be the potential cost savings from the increased productivity of the IVSS-equipped plows. This benefit equals the increased lane miles able to be plowed with these plows, times the cost of plowing with conventional plows. However, unlike the benefits to the public described above, this benefit would not be restricted to the times when only the IVSS-equipped plows are capable of plowing.

Most of the economic benefits of the IVSS-equipped plows would be expected to result not from the increased speed at which they are likely to be able to plow, but from their ability to plow during snow and ice conditions when conventional plows cannot operate. These benefits would

[7] 5th International Symposium on Snow Removal and Ice Control Technology (Eastern Snow Expo), Roanoke, Virginia, Sponsored by Transportation Research Board Committee A3C09, "Winter Maintenance," September 5-9, 2000; and 9th AASHTO/TRB Maintenance Management Conference, Juneau, Alaska, Sponsored by American Association of State Highway and Transportation Officials (AASHTO) Highway Subcommittee on Maintenance and the Transportation Research Board (TRB) Group 3 Section C Maintenance CommitteesJuly 16-20, 2000

allow the general public (including trucks) to travel more safely and faster at times when unequipped plows cannot plow.

As noted at the beginning of this section, the key to evaluating these public safety and mobility benefits would have been data from the FOT on the type, frequency, and duration of the weather conditions under which the new plows could provide these benefits, where conventional plows could not. If the benefits only resulted from faster plowing (more lane miles plowed) regardless of weather condition, the service levels to the public could be held constant and the economic evaluation would simply compare the costs per mile of plowing between equipped and unequipped plows (including the cost of crashes involving snowplows). However, this is not the case; service levels to the public are not the same with the two types of plows, with the result that the increased productivity of the plows is only one of several benefits of the new plows. But to the extent that the IVI-equipped plows can plow faster than conventional plows under a variety of weather conditions (but likely not all conditions), the cost savings from not plowing the increased lane miles plowed with conventional plows is an important economic benefit. As noted before, it would be expanded using FHWA national statistics on lane miles by type of road in states in the various categories of winter storm severity.

Finally, it should be noted that the added costs of plows equipped with the IVI technology enters into the benefit/cost analysis on the cost side. That is, a pure cost per mile comparison of plowing with equipped versus unequipped plows may or may not favor the presumably faster, safer, but more expensive IVSS-equipped plows. However, for the reasons explained above, the differences in the benefits to the general public must also be factored in and expanded nationally to evaluate whether the benefits of the IVI equipped plows to the public are worth the extra costs to the public of the IVI technology.

The specific hypothesis to be tested in a BCA is that values of the combined benefits to society of developing, deploying, and maintaining each of the IVSS is more than the costs of these systems. Therefore, all the benefits and costs input to a BCA must have some inherent value to society. While the actual summing of the benefits and costs in a BCA is straightforward, identifying the right inputs and observing or estimating their values is not. In particular, for a benefit or cost to be included in a BCA, it must be

- Quantifiable,
- Monetizable,
- Not duplicative, and
- Not a transfer.

Benefits must be quantifiable in order to attach a monetary value to them. However, not all quantifiable benefits have economic value to society. Not duplicative means that benefits and costs cannot be double counted, even though they may appear to some not to be duplicative. And, finally, transfers between affected groups are not net charges to society and therefore cannot be included in a BCA.

The process of valuing the benefits needs to consider the way values are customarily placed on such benefits as crashes avoided, travel time saved, vehicle "productivity," etc. The values in the literature can include a wide range of benefit elements. The elements that make up these valuations in the literature would be explicitly identified in order to avoid double counting or omitting a benefit.

Finally, to test the hypothesis that the IVI systems have net benefits to society, all present and future discounted costs must be subtracted from their properly discounted present and future benefits to society. Each of the benefits and costs in a BCA is discounted to a present value over the economic life of a project. For the FOTs, benefits are assumed to begin immediately with the one-time start-up costs in the year 2001 and extend for a 20-year period through 2021. This assumption allows 20 years of economic returns for the project, which would include one or more replacement cycles for equipment and software at appropriate intervals.

The benefits planned for inclusion in this BCA are as follows:

- Crashes avoided,
- Improved emergency response,
- Travel time savings,
- Possible cost savings from faster, less stressful snowplowing, and
- Reduced air/noise/HAZMAT pollution.

The costs planned for inclusion in the BCA are:

- One-time startup costs,
- Replacement capital costs, and
- Increased operating costs.

All of the benefits and costs proposed to be included in this BCA would be the result of changes in the snowplow operations and the conditions of the roads being plowed, relative to how and with what vehicles and equipment the roads were previously plowed. The evaluation measures determine the type of data that need to be collected and analyzed in this evaluation. The process of identifying the benefit measures listed above is described next for each of the five traditional ITS goal areas (safety, mobility, efficiency, productivity, and environmental quality).

Since the five ITS goal areas double count some benefits, and include benefits that make no contribution to economic efficiency (and, thus, have no economic value), only four of the five ITS goal areas include potential benefits (or disbenefits) that should be input to this BCA. The reasons for this are explained below under efficiency benefit measures.

Table 6-9 summarizes the candidate benefit measures for the Mn/DOT IVI FOT. The table also describes the methods and information sources proposed to obtain the required data for each measure, as well as the role of the literature search required for this evaluation. Expanding the results of the BCA nationally would require the considerable additional information described previously.

Table 6-9. Benefit Measures and Information Sources for Mn/DOT FOT

Goal	Benefit Measure	Information Source	Literature Search
Safety	Reduced numbers and severity of crashes involving snowplows or other specialty vehicles.	Crash avoidance analysis (statistical modeling), snowplow accident records, driver/ supervisor interviews, and highway maintenance records.	Value of snowplow and other specialty vehicle accidents.
	Reduced numbers and severity of crashes involving the public by type and severity (PD/PI/fatality) and by type of vehicle involved.	Changes in plowed road conditions from driver/ supervisor interviews. Volume counts/records by plowed road conditions plus induced travel from the mobility benefit.	Accident rates by plowed road condition; value of accidents avoided.
	Lives saved, injury severity reduced, property damage saved from improved emergency response times.	Same, plus EMT and fire department interviews to estimate improved response times.	Effect of emergency response times on these benefit measures, value of lives saved, etc.
Mobility	User benefit from travel time and cost savings on better-plowed roads by type of vehicle (auto/truck)	Snowplow driver/supervisor and police interviews to obtain the frequency of dispatching IVI-equipped vehicles in adverse conditions, which changes the distribution of plowed road conditions (including road closures). Highway speeds by plowed road condition. Volume counts/records by plowed road conditions.	Possible information on speeds and operating costs by plowed road condition; value of travel time by type of vehicle and road condition.
	User benefit from induced travel due to improved travel times on better-plowed roads by type of vehicle.	Same, plus demand elasticities to estimate induced travel.	Same, plus demand elasticities to estimate induced travel.
	User benefit from fewer accident caused delays.	Crash reduction estimates. Literature values of crash related delays to public.	Incident caused delays (ideally under adverse weather conditions); values of travel time.

Goal	Benefit Measure	Information Source	Literature Search
Productivity (cost savings)	Net cost savings from faster plowing.	Increased miles plowed per snowplow hour from driver logs minus any increases in crash costs to snowplows. Driver/supervisor interviews; accident costs involving snowplows from above.	
	Cost savings from reduced snowplow driver turnover.	Driver/supervisor interviews and records.	
	Cost savings from reduced infrastructure damage from snowplows.	Accidents involving snowplows from above.	Possible information on snowplow crashes and their costs.
	Cost savings from improved emergency response times.	Driver/supervisor interviews and records.	
	Cost savings from reduced salt or de-icing chemical use.	Supervisor interviews and maintenance records.	
	Cost savings from fewer emergency response calls.	Accidents of all kinds from above. Driver/supervisor interviews and records.	
Environmental Quality	HAZMAT crashes avoided.	HAZMAT crashes from above.	Environmental costs of a HAZMAT crash (likely to be included in total crash cost).
	Reduced air and noise pollution.	Emission rates related to speeds of plows and general traffic; speed and volume changes from above.	Emission rates by speed and type of vehicle; value of pollution by type.
	Reduced salt and de-icing chemical pollution.	Supervisor interviews and maintenance records.	Unit values of salt and de-icing chemical pollution in winter.
	Same, but from snowplow crashes.	Accidents involving snowplows from above. Supervisor interviews.	Same.
	Fuel consumption changes.	Consumption rates related to speed and type of vehicle. Changes in speed and volumes from mobility analysis above.	Consumption rates by speed, type of vehicle and (ideally) road condition. Externality value of fuel consumption.

7.0 OBSERVATIONS AND LESSONS LEARNED

The lack of snow and low visibility conditions during the winter of 2001-2002 was the principal reason that the evaluation of the Mn/DOT IVI FOT was not carried out in accordance with Battelle's November 1, 2001 evaluation plan. Nevertheless, the experiences of planning and executing the data collection activities resulted in a number of "observations" and "lessons learned" that may be useful to researchers planning subsequent studies. These observations are presented from the perspective of the independent evaluator and do not necessarily represent the views of the FOT partners or the U.S. DOT.

Pre-FOT System Testing and Validation

Although most of the component technologies that were tested in the FOT evolved from versions deployed in earlier FOTs, the performance of the complete system, including the data acquisition system and the driver-vehicle interface was not fully understood or documented before the start of the FOT. In March 2002, four months after the start of the FOT, the University of Minnesota published a draft Validation Report which documented the performance of the system components. However, because of the delays in completing the system development, the findings in this report were not known at the start of the FOT. Furthermore, the scope of testing focused primarily on the capabilities of the components. It would have been helpful to expand the scope to include tests of the overall system performance, including the use of simulated incidents such as road departures and rear-end encounters. Such tests should be done while exercising the data acquisition system. In February 2002, Battelle proposed test plans for supplemental evaluation studies that focused on documenting system performance under a variety of driving and road conditions. Battelle's plan (See Appendix F) also recommended a series of tests to evaluate the driver's ability to rely on the vision enhancement system. It is recommended that tests of this type be performed and evaluated prior to the full scale FOT deployment. Examples of some of the issues that arose during the FOT, and possibly could have been alleviated with up-front testing, are summarized below.

Choice of Technologies

An important question for anyone who wishes to understand this FOT concerns the technologies? Can they be utilized in other locations? If so, with what assumptions? Most of the focus of this evaluation was on performance of the in-vehicle technologies, but there was substantial infrastructure that was installed to support the FOT, including three DGPS correction stations, six weather stations, and magnetic tape. Garage support facilities were also an important part of the FOT. The following paragraphs explore the infrastructure that was required and consider the implications for expanding these IVSS technologies.

The technologies chosen for the FOT were predominantly off-the-shelf products. There may have been alternative technologies that were capable of achieving the same results much of the time, but they would not have worked as well under all circumstances. For example, optical guidance was a proven alternative to the FOT's GPS-based and magnetic lateral guidance technologies for lanekeeping, but the optical technology would not work where snow covers lane markings or blowing snow obscures visibility. At the time of the FOT, differential GPS and its associated correction signal communications had attained sufficient accuracy for lanekeeping and mapping of certain roadside obstacles. The front-looking and side-looking radars were technologies in commercial use. The technology behind the Head-up Display was increasing in military and commercial use, although primarily in a different configuration that projects directly onto a windshield (which Mn/DOT's design constraints did not appear to accommodate). The technologies appeared to be rugged enough to withstand the harsh environment of cold temperatures, salt, grit, and vibration to which they were subjected.

The FOT vehicle technologies were not stand-alone. If one of the equipped specialty vehicles was driven onto a road that had not been mapped into a geospatial database or which fell outside the limited range of GPS correction stations set up to serve it, its core driver assistive system would not work. In fact, that was the case whenever a specialty vehicle was operating in the vicinity of the test area but off of the TH-7/County Road-7 test roads.

None of the FOT technologies – if unused - would restrict a driver's normal operation of the vehicle (except for minor inconveniences caused by equipment placement, perhaps). After all, drivers in the FOT were given the freedom to not use the IVSS technologies if they preferred, or to use only part of them (like the haptic lane-departure warning alone). What *would* be lost in a vehicle off of a mapped road are the GPS-based lanekeeping assist via visualization; the haptic, audible, and visual alarms; and the forward-looking radar's ability to discriminate between fixed and other obstacles. The forward-looking and side-looking radars and associated collision warnings would remain available. In any deployment beyond the FOT and outside of other testing (i.e., in typical working conditions), there would not be a need to have the vehDAQ for recording driving data.

GPS Problems

The greatest deterioration in system performance arose from problems with the GPS navigation system. The GPS problems manifested themselves as (1) loss of GPS correction signals in certain areas of TH-7 and County Road 7, and (2) problems with signal loss when vehicles were transiting a "transition zone" located at the mid-point between two of the GPS correction stations. Both of these GPS-related problems (particularly the second) might have been corrected if there had been more time available to test and debug (the practice of the FOT was to freeze the design for the FOT unless there were safety issues involved). As it was, the FOT went operational on December 22, 2001 at nearly the halfway point of the planned FOT performance period (October 1, 2001 to March 31, 2002).

The loss of GPS signal quality would have caused most of the driver assistive technologies to cease; the only remaining driver aids would be the forward- and side-looking warning systems, but the forward-looking system would likely have been flooded with unfiltered data. The problem with loss of GPS signal was reported to have occurred in areas of irregular geography around St. Bonifacius on TH-7, and in the vicinity of a stand of trees near Bear Lake on County Road 7. If the driver happened to be on either of the two roadway sections with magnetic tape when GPS quality was lost, then magnetic lateral guidance should have displayed on the HUD if the combiner were not folded up.

Wherever differential GPS-based lanekeeping teachnologies of this type may be used, GPS mapping would have to be conducted. However, in the course of preparing for the FOT, University of Minnesota personnel found quicker and more economical ways of carrying out the mapping than their initial approaches.

Magnetic Lateral Guidance

The roadway magnetic tape/sensor-based system was a backup method of vehicle lane positioning. The guidance that this system provided was displayed only when the GPS correction signal quality deteriorated or was lost. If that occurred when the specialty vehicle happened to be on one of the two roadway sections that had the magnetic tape installed, the magnetic tape/sensor system provided local positioning information in the form of lateral displacement of the vehicle from the lane's center. The magnetic tape was installed on a total 12 miles of roadway located in the operating areas of the Hutchinson and McLeod County snowplows. The magnetic lateral guidance would be available until GPS signal quality was restored for the primary lane keeping system.[8] Table 7-1 illustrates that only two of the vehicles (both snowplows) had magnetic lateral guidance for more than 1-½ minutes total. Thus, this technology hardly saw any use during the FOT. Drivers said little about this component of the IVSS but it seemed to work reasonably well for the few who had an opportunity to use it.

Table 7-1. Magnetic Lateral Guidance Usage

	Time with Guidance Provided by Magnetometer (seconds)	
Vehicle	**Left**	**Right**
Ambulance	0	41.9
Patrol	0	82.3
Eden Prairie	0	0
Hutchinson	130.2	710.5
McLeod	470.4	0
Shakopee	0	0

The magnetic tape and lateral positioning sensor represented customization. The magnetic sensor and tape combination were a backup (to GPS-based) guidance system, and therefore an optional technology. However, it could be helpful in areas where the GPS signal is lost when the vehicle passes under bridges, near some stands of trees, or in an area of geographic or man-made features that interfere with receipt of the GPS correction signals. Drivers speculated that in the future, an economical use of the magnetic tape/sensor system may be to install the magnetic tape specifically in areas where the GPS signal is known to have problems. Use of the tape on a limited basis in such areas would not be nearly as expensive as installing the tape along unbroken miles of roadway.

Driving Time

Figure 7-1 shows the total amount of driving time for each driver for which the data acquisition system was collecting on-board driving data. This time should generally coincide with the amount of driving time each driver had access to the IVSS – in all weather conditions. This time is divided into two categories: System Off time and System On time. No attempt was made to determine whether the System On time was recorded under adverse weather conditions. Instead, this information is provided as background. It shows that most of the drivers had at least some

[8] The ambulance and patrol car had only one magnetometer, which was on the right side of the bumper. The snowplows had two magnetometers, one on each side of the bumper, which would have been different distances from the magnetic tape and thus could produce differences between right and left readings if the numerical sensor value dropped at one of them. The McLeod County snowplow's right sensor always displayed "error".

experience operating their vehicles with the IVSS system activated. The duration of this experience ranges from a few minutes to approximately 21 hours. Overall, the system was turned on approximately 25 percent of the time it was available to the drivers. Five snow plow drivers have the most experience (between 5 and 21 hours each). Only two ambulance drivers have more than one hour of driving experience with the system on.

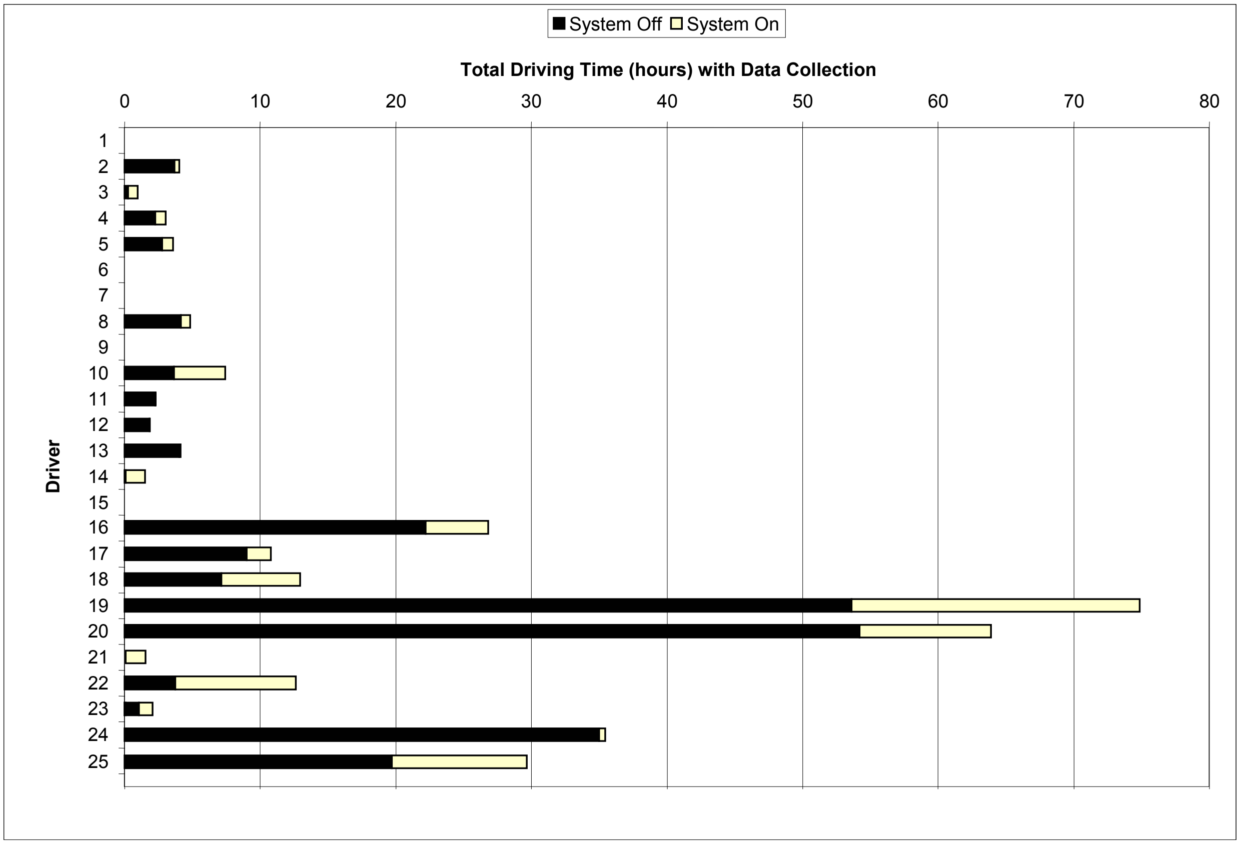


Figure 7-1. Driving Time with System Off and System On – by Driver

Figure 7-2 shows the amount of time each driver was operating his/her vehicle with the system turned on. The time is divided into two categories: Volume off (volume level zero) and volume on (volume level 1 through 11). Only three drivers (two ambulance drivers and one snowplow driver) had any significant driving experience (between 1.6 and 4.9 hours) with the volume turned on. The significant issue is that nearly all of the other drivers chose not to turn on the audible alarm. These findings are consistent with the drivers' express concerns about using the audible alarm.

Several drivers during the interviews mentioned ghost objects that appeared on the HUD as forward collision warning hazards. The symbology would sometimes appear to cross from one side of the road to another, but the driver could verify that there was no actual object where the symbology indicated there was.

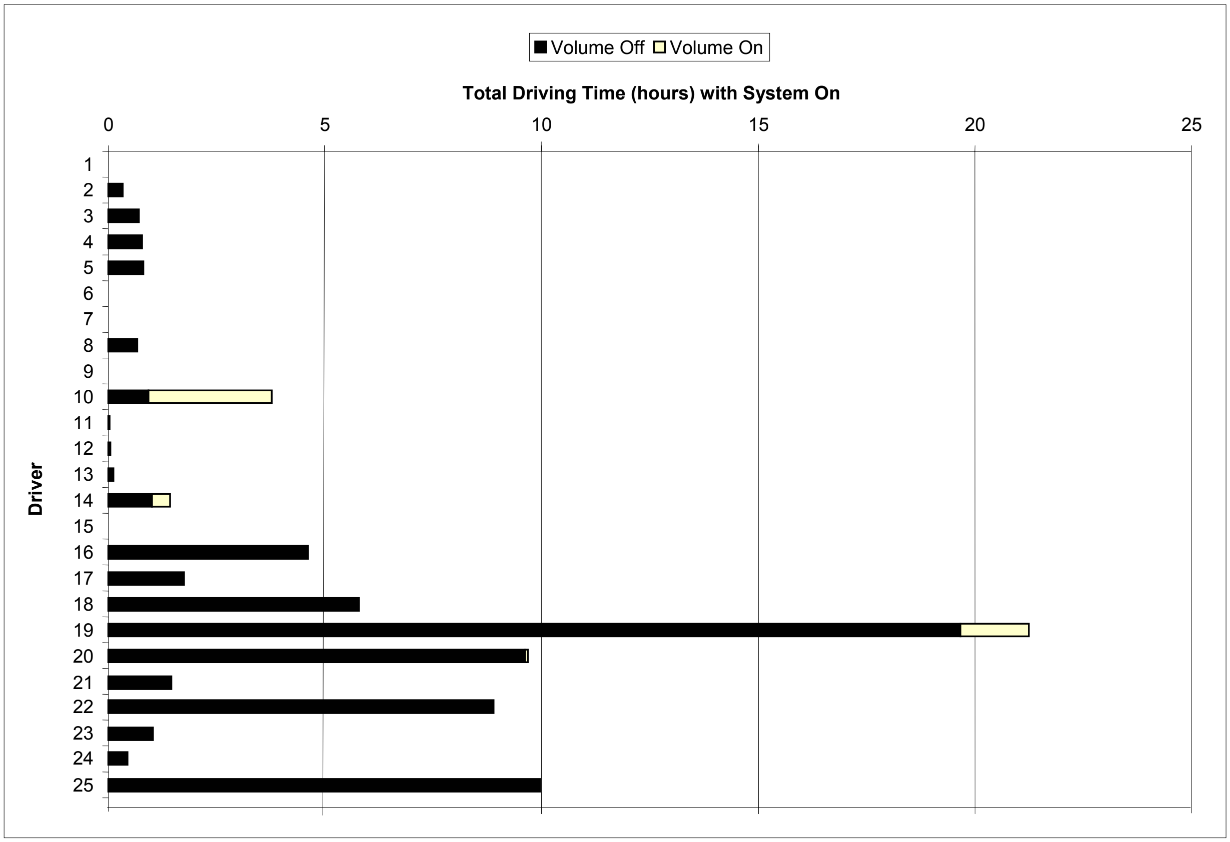


Figure 7-2. Driving Times with Volume Off and Volume On While System was Turned On – by Driver

Driver Acceptance

As noted in the Executive Summary of the Battelle White Paper – *Mn/DOT Driver Acceptance: IVI FOT Evaluation Report*, "This evaluation of driver acceptance was hampered by both the lack of low visibility weather 'events' and the initially inadequate integration and performance of some of the IVI technology systems in each of the three specialty vehicle categories. Because of these factors, driver perceptions measured by these surveys and interviews are more likely to reflect their frustrations and concerns with the circumstances of the test than with the actual functionality and safety benefits to be derived from the technologies.

"Nevertheless, drivers and supervisors remained generally optimistic that, if the technology problems can be resolved, the IVSS technologies hold significant potential to enhance driver confidence and performance while operating specialty vehicles under very difficult driving conditions. The participants in this test agreed that the technical problems with the IVSS needed to be fixed and more evaluation time under adverse weather conditions was needed to confirm and quantify benefits."

Dual Evaluations

This FOT was accompanied by two parallel evaluation efforts. Battelle conducted an independent evaluation in accordance with evaluation goals set forth by the U.S. DOT. At the same time, the University of Minnesota carried out its evaluation while serving as the systems integrator for Mn/DOT. Because both evaluation teams intended to use the same data, it was necessary to collaborate and reach consensus on various issues. In particular, the teams had to agree on an experimental design, procedures for interacting with the drivers, and types of engineering and operations data to be collected.

During the planning phase (September 2001) Battelle met with the Mn/DOT partners to discuss the experimental design. The original research plan proposed by Mn/DOT called for four snowplows to be fully equipped; but only two would have active IVSS. However, to meet the evaluation needs of the University, it was best to have the systems active at all times. On the other hand, for Battelle's safety benefits analysis, it was best to alternate active and inactive systems on each vehicle during the entire test period. In the end, a compromise plan was developed. A detailed discussion of this plan is presented in Section 2.2.2.

Battelle and the University collaborated on their interactions with the drivers. The University conducted the driver orientation sessions; but invited Battelle to attend and explain the purpose and plan for the independent evaluation. Both teams had opportunities to interview the drivers separately and conduct related data collection activities (e.g., Battelle's internet survey). Although the drivers may have been asked similar questions by both parties, the participation of both organizations during the orientation session helped to avoid confusion or concerns on the part of the drivers.

The one area where more (and earlier) collaboration between the independent evaluator and the partnership was needed was in the development of the on-board data acquisition system. Shortly before the start of the FOT, Battelle was given the opportunity to review the data collection plan. Some of Battelle's recommended changes were implemented; however, Battelle's recommendation to include data elements that indicate when various audio, haptic, and visual signals are being sent to the driver was not implemented in the final data acquisition system. This type of data is needed for various safety benefit, system performance, and human factors analyses. Battelle recommends that decisions concerning the data acquisition system be made earlier in the planning phase and involve all parties that have an interest in the outcomes of the evaluation efforts (e.g., Mn/DOT and the U.S. DOT).

REFERENCES

5th International Symposium on Snow Removal and Ice Control Technology (Eastern Snow Expo), Roanoke, Virginia, Sponsored by Transportation Research Board Committee A3C09, "Winter Maintenance," September 5-9, 2000.

9th AASHTO/TRB Maintenance Management Conference, Juneau, Alaska, Sponsored by American Association of State Highway and Transportation Officials (AASHTO) Highway Subcommittee on Maintenance and the Transportation Research Board (TRB) Group 3 Section C Maintenance Committees, July 16-20, 2000

Acton, W. H., & Colle, H. A. (1984). The effect of task type and stimulus pacing rate on subjective mental workload ratings. Proceedings of the IEEE 1984 National Aerospace and Electronics Conference, 818-823.

Anthony, C. R., & Biers, D. W. (1997). Unidimensional versus multidimensional workload scales and the effect of number of rating scale categories. Proceedings of the 41st Annual Meeting of the Human Factors and Ergonomics Society, 1084-1088.

Armstrong Aerospace Medical Research Laboratory (AAMRL). (1987). Subjective Workload Assessment Technique (SWAT): A User's Guide. Dayton, OH: AAMRL, Wright-Patterson AFB.

Bajikar, S., Gorjestani, A., Simpkins, P., & Donath, M. (1997). Evaluation of in-vehicle GPS-based lane position sensing for preventing road departure. 1997 IEEE Conference on Intelligent Transportation Systems.

Battelle, (2000). Safety Benefits Estimation Methodology for the IVI Generation O Field Operational Tests, Draft report to U.S. DOT, Contract DTFH61-96-C-00077, Task Orders 7718 to 7721, November, 2000.

Battelle (2001c). Evaluation Plan for the Mn/DOT Intelligent Vehicle Initiative Field Operational Test (Draft Version 1.0), prepared by Battelle for U.S. DOT, Contract No. DTFH61-96-C-00077, Task Order 7720, November 1, 2001.

Battelle (2002a). Summary Data Report of Driver Survey and Interview Data, prepared by Battelle for U.S. DOT, Contract No. DTFH61-96-C-00077, Task Order 7718, February 14, 2002.

Battelle (2002b). Volvo Baseline Driver Survey, prepared by Battelle for U.S. DOT, Contract No. DTFH61-96-C-00077, Task Order 7721, April 5, 2002.

Biers, D. W. (1995). SWAT: Do we need conjoint measurement? Proceeding of the 39th Annual Meeting of the Human Factors and Ergonomics Society, 1233-1237.

Booz-Allen & Hamilton Inc. (1999) Evaluation of the Minnesota Department of Transportation's Intelligent Vehicle Initiative Snowplow Demonstration Project on Trunk Highway 19 Winter

1998-1999. Minnesota DOT (Minnesota Guidestar) report by Booz-Allen; McLean, Virginia, October 27, 1999. Available at www.dot.state.mn.us/guidestar/ivihwy19.html.

Christ, R. E., Hill, S. G., Byers, J. C., Iavecchia, H. M., Zaklad, A. L., & Bittner, A. C. (1993). Application and validation of workload assessment techniques (Report No. 974). U.S. Army Research Institute for the Behavioral and Social Sciences.

Draft Validation Report, Intelligent Vehicle Initiative Specialty Vehicle Field Operational Test, Mn/Dot Partners, March 2002.

Eggemeier, F. T., Crabtree, M., Zingg, J., Reid, G., & Shingledecker, C. (1982). Subjective workload assessment in a memory update task. Proceedings of the Human Factors Society 28th Annual Meeting, 643-647.

Eggemeier, F. T., McGhee, J. Z., & Reid, G. (1983). The effects of variations in task loading on subjective workload rating scales. Proceedings of the IEEE 1983 National Aerospace and Electronics Conference, 1099-1106.

Eggemeier, F. T., & Stadler, M. (1984). Subjective workload assessment in a spatial memory task. Proceedings of the Human Factors Society 28th Annual Meeting, 680-684.

Evaluation Report Volume 1 – System Performance and Human Factors, Intelligent Vehicle Initiative Specialty Vehicle Field Operational Test, Mn/DOT Partners, July 2002.

Evaluation Report Volume 2 – Benefit Analysis, Intelligent Vehicle Initiative Specialty Vehicle Field Operational Test, Mn/DOT Partners, December 2002.

FHWA (1997). Summary of SHRP Research and Economic Benefits of Snow and Ice Control, U.S. Federal Highway Administration, December 1997.

FHWA (2001a). Highway Statistics 1999: Office of Highway Policy Information, web site of Federal Highway Administration (U.S. DOT), accessed October 2001. http://www.fhwa.dot.gov/ohim/hs99/roads.htm

FHWA (2001b). Winter Maintenance Exchange: Kentucky, web site of Federal Highway Administration (U.S. DOT), accessed October 2001. http://www.fhwa.dot.gov/winter/exchange/states/kentucky.html

Hill, S. G., & Harris, R. M. (1990). OWLKNEST: A knowledge-based expert system for selecting operator workload techniques. In W. Karwowski, A. M. Genaidy, & S. S. Asfour (Eds.), *Computer*-aided design: A researcher's guide (pp. 213-225). London: Taylor & Francis.

Hill, S.G., Iavecchia, H.P., Byers, J.C., Bittner, A.C., Zakland, A.L. and Christ, R.E. (1992). Comparison of four subjective workload rating scales, Human Factors, 34, 429-439.

Knapp, K., Kroeger, D., and Giese, K. (2000). Mobility and Safety Impacts of Winter Storm Events in a Freeway Environment, final report prepared by Iowa State University (Ames, Iowa) for Iowa DOT, Project TR-426 (February 2000).

Kroemer, K. H. E. and Grandjean, E. (1997). Fitting the Task to the Human (5th ed.). London, UK: Taylor & Francis.

Lay, Michael, and Donald Williams (1997). Hook lifts and brine: innovative snow and ice control, Public Works, vol. 128, no. 8, pg. 62 (July 1997).

Linn, H. M., Newstrom, B., Shankwitz, C., & Donath, M. (1999). A heads up display based on a DGPS and real time accessible geo-spatial database for low visibility driving. Proceedings of the 12th International Meeting of the Satellite Division of the Institute of Navigation (IONGPS '99), Nashville, Tennessee (September).

Linn, H. M., Newstrom, B., Shankwitz, C., & Donath, M. (2000). A heads up display based on a DGPS and real time accessible geo-spatial database for low visibility driving. Proceedings of the 5th International Symposium on Advanced Vehicle Control (AVEC 2000), Ann Arbor, Michigan.

Mn/DOT Driver Acceptance: IVI FOT Evaluation Report, Battelle White Paper, June 30, 2003.

Montana DOT (2001). Maintenance Goals and Objectives, on state DOT web site, accessed October 2001. http://www.mdt.state.mt.us/departments/maintenance/goals_objectives.html

NHTSA (1996). Preliminary Human Factors Guidelines for Crash Avoidance Warning Devices, National Highway Traffic Safety Administration, Washington, D.C., January 1996.

Nixon, Wilfred (unpublished). Winter Transportation Problems: Identifying Strategies to Improve Safety and Reduce Economic Burdens, project by Iowa State University (Ames, Iowa) for Iowa Department of Transportation, Midwest Transportation Center (1991 to 1994).

NOAA (2001). Comparative Climatic Data on the NOAA's National Virtual Data System website, accessed October 2001.
http://nndc.noaa.gov/?http://ols.nndc.noaa.gov:80/plolstore/plsql/olstore.prodspecific?prodnum=C00095-PUB-A0001

Ohio DOT (2001). Office of Maintenance Administration, Maintenance Section, ODOT Snow and Ice Program, on state DOT web site, accessed October 2001.
http://www.dot.state.oh.us/maintadmin/odot_snow_and_ice_program.htm

Oshkosh (2001). Personal communication between Vincent Brown, Battelle; and a representative of Oshkosh Truck Corporation, Oshkosh, Wisconsin, October, 2001.

Potter, S., & Acton, W. (1985). Relative contributions of SWAT dimensions to overall subjective workload ratings. In Proceedings of Third Symposium on Aviation Psychology. Columbus, OH: Ohio State University.

Public Sector Consultants, Inc. (1993), The Use of Selected Deicing Materials on Michigan Roads: Environmental and Economic Impacts, prepared for Michigan DOT, Appendix A, Survey of Motorists, December 1993.

Reid, G. B., & Colle, H. A. (1988). Critical SWAT values for predicting operator overload. Proceedings of the Human Factors Society 32nd Annual Meeting, 1414-1418. Santa Monica, CA: Human Factors Society.

Reid, G. B., Potter, S. S., & Bressler, J. R. (1989). Subjective Workload Assessment Technique (SWAT): A user's guide *(U)* (Report No. AAMRL-TR-89-023) Harry G. Armstrong Aerospace Medical Research Laboratory.

Reid, G. B., Shingledecker, C. A., & Eggemeier, F. T. (1981). Application of conjoint measurement to workload scale development. Proceedings of the Human Factors Society 25th Annual Meeting, 522-525.

Sheridan, T. B., & Simpson, R. W. (1979). Toward the definition and measurement of the mental workload of transport pilots (FTL Report R79-4). Cambridge, MA: Flight Transportation Laboratory.

U.S. Census Bureau (2000), Statistical Abstract of the United States: 2000, citing U.S. National Oceanic and Atmospheric Administration, Comparative Climatic Data, Table No. 413, Snow and Ice Pellets—Selected Cities, pg. 249, U.S. Department of Commerce, web site: http://www.census.gov/prod/www/statistical-abstract-us.html, accessed December 2001.

U.S. Census Bureau (2001a), Ranking Tables for States: Population in 2000, U.S. Department of Commerce, web site: http://www.census.gov/population/www/cen2000/phc-t2.html, accessed October 2001.

U.S. Census Bureau (2001b), State & County QuickFacts, U.S. Department of Commerce, web site: http://quickfacts.census.gov/qfd/index.html, accessed October 2001.

U.S. DOT. (1999). PROSPECTUS – Evaluation of the Intelligent Vehicle Initiative (IVI) Generation 0 Field Operational Tests. Request for Proposal DTFH61-96-C-00077. Task 7720.

Vidulich, M.A., and Tsang, P.S. (1987). Absolute magnitude estimation and relative judgment approaches to subjective workload assessment. In Proceedings of the Human Factors Society 31st Annual Meeting (pp. 1057-1061). Santa Monica, CA: Human Factors Society.

APPENDIX A

Design & Changes/Maintenance/Complaint Log

TH 7 Intelligent Vehicle Initiative (IVI)
(Cooperative Agreement: DTFH61-99-X-00101)
Monthly Field Operational Test Status Report
Design & System Changes/Maintenance/Complaint Log

Date Vehicle 1st Turned on as Operational

Reporting Month
January 2002 *revised*

Eden Prairie Snowplow	*Shakopee Snowplow*	*Hutchinson Snowplow*	*McLeod County*	*Ambulance*	*State Patrol*
12/22/01	12/22/01	12/22/01	12/22/01	12/22/01	12/22/01

1. Driver Assistive System

Record of Design & System Changes

Date	*Test Vehicle Type*	*Modification made to Driver Assistive System and Reason*
12/24/01	Eden Prairie Snowplow	The VehDaQ dll's were corrupted due to power cycling on and off. The VehDAQ software was reloaded and tested.

Maintenance Log

Date	*Test Vehicle Type*	*Component Replaced/Software Changes*
12/24/01	Eden Prairie Snowplow	The combiner was loose. The combiner mount was repaired and a new strap was installed to hold the combiner when the system is not in use.
12/26/01	Hutchinson	There was no power and erratic power on the Hutchinson Snowplow. The inverter was held on with small fasteners, which failed. The inverter dropped and took power relays with it. Replacing the old power relays with new ones and remounting the AC inverter solved the problem.
12/28/01	McLeod County Snowplow	A new radar filter was installed to address the bug in the radar software processing.
12/26/01	Hutchinson	There was no power and erratic power on the Hutchinson Snowplow. The inverter was held on with small fasteners, which failed. The inverter dropped and took power relays with it. Replacing the old power relays with new ones and remounting the AC inverter solved the problem.
1/7/02	State Patrol	The vehDAQ software on the state patrol vehicle was not recording, the DLLs were corrupted. To solve the problem the vehDAQ software was reinstalled.
1/9/01	Shakopee Snowplow	There was no power to the system. The "hot" wire to the power relays was dangling. The wire was reconnected to another wire under the dash keyed with ignition.
1/10/01	Hutchinson	The Hutchinson truck after the software upgrade produced false radar targets. It was discovered that the yakima bar did not receive the stabilizer bolt. The stabilizer bolt was replaced and the radar re-aimed. The system is much improved.
1/15/02	State Patrol	There were reports that the vehDAQ system was not recording. Investigation indicated that it was a bad microphone. The microphone was replaced.
1/15/02	Hutchinson Snowplow	The Hutchinson truck had problems starting up due to a bad solder joint on the power cable connected to the computer "snowplow 1." To prevent future problems all connections were resoldered leading to the computers.

2. IVI Infrastructure

Record of Design & System Changes

Date	***Infrastructure Type*** (Tower Equipment, Weather Stations, etc.)	***Modification made to Infrastructure***
1/11/02	Software	Version 3.02 was installed, which delays the broadcast of the CMR correction message 0.5 seconds. This enabled the removal of SBC which was controlling the broadcast of the CMR messaging.
1/11/02	Base Station	The SB command in the modem was turned to ON. The SP delay count was changed from 25 to 2, which decreases the time out wait for a re-broadcast if one tower broadcast "collides" with another. This drastically improved system performance.

Maintenance Log

Date	***Infrastructure Type*** (Tower Equipment, Weather Stations, etc.)	***Infrastructure Replaced/ Changes to Infrastructure***
1/22/02	Chanhassen Base Station	At 1 Hz the CMR was not being broadcast. A separate process was being run on that receiver. That process was killed and the receiver returned to normal.

3. Record of Complaints

Date Received	***Test Vehicle Type***	***Date Responded/ Resolved***	***Complaint & Resolution***
1/15/02	Shakopee	1/15/02	Driver complained of blown fuses. The driver indicated that the problem couldn't be replicated and moved the system relay "hot" wire to the power wire just in case.
1/7/02	State Patrol	1/7/02	There were complaints that the HUD didn't display the correct colors. The complaint was investigated and it revealed a broken VGA cable. The VGA cable was replaces and an extra was run in parallel because exchange requires the removal of the back seat.
1/7/02	State Patrol	1/7/02	There were complaints that the combiner shakes. It was recommended that all thumbscrews be tightened securely.

4. General Problems/Issues/Comments/Notes

Problems/Issues/Comments/Notes
➢ On December 28, 2001, the radar process in the Eden Prairie truck would die after running an hour. The hour turned out to be coincidence, but was a very good lead to locate the problem. It appears that a stray point in the geospatial database, which had no attributes, caused the radar processor to choke. An error handler was added, and then the system tested fine. Problem solved.

Completed By	***Date***
Daryl Taavola and Tina Roelofs	2/13/02

cc: Brad Estochen – Mn/DOT, John Scharffbillig – Mn/DOT, Sheila Johnson – Mn/DOT, Gary Nourse – 3M, Dave Thiede – Altra Technologies, Kathleen Harder – U of M, Bill Tate – Battelle, Daryl Taavola – URS

APPENDIX B

Consent Form and vehDAQ Data Chain of Custody

APPENDIX B: UNIVERSITY OF MINNESOTA
CONSENT FORM
Investigating the Effects of
Driver Aids On Driver Behavior - Field Operational Test

In this study, we are investigating the effect of driver aids on driving performance. Please read this form before agreeing to be in the study. We will be happy to answer any questions you might have.

Kathleen Harder and John Bloomfield, the research scientists who are in charge of this study, both work in the Program for Human Factors Interdisciplinary Research in Simulation and Transportation at the University of Minnesota.

Background Information: The purpose of the study is to find out how driving aids affect driving performance. Data will be collected while you are driving. Also, you will be videotaped while you are driving.

Procedures: During your time here you will drive the test vehicle along a predefined course.

Risks and Benefits of Being in the Study: The risks you will encounter in this field test are similar to those you face in the normal course of driving. In the event that this research activity results in an injury, treatment will be available, including first aid, emergency treatment and follow-up care as needed. Care for such injuries will be covered by Workman's Compensation. If you think that you have suffered a research-related injury, please let the research scientists know right away.

There are no direct benefits to you for participating in this study.

Confidentiality: The data we collect while you are driving will be kept confidential (except as governed by law). In any presentation or account of this study, your name will never be used and we will not provide any information that would make it possible to identify you. Kathleen Harder, John Bloomfield, Ben Chihak, Marcie M. Hibner, Jessica Sanford, Brian J. Scott, Gregory V. Stark, William H. Tate, and Darlene E. Wells will be the only people who have access to your data.

The people listed above will also be the only people who have access to the videotapes. We may want to use one or two brief video extracts in a presentation—if we would like to use part of your tape, we will contact you to obtain your permission first. When the report of the study has been completed, the videotape of your session will be destroyed.

Voluntary Nature of the Study: If you decide to participate, you are free to withdraw at any time without consequence. Your decision about whether or not to participate will not affect your current or future relations with the University of Minnesota.

Contact and Questions: You may ask any questions at any time during the study. If you have questions after you have finished driving the test vehicle, you may contact Dr. Kathleen Harder at 1100 Mechanical Engineering, 111 Church Street S.E., University of Minnesota, Minneapolis, MN 55455. Phone: 612-626-0026.

If you have any questions or concerns about the study and would like to talk with someone other than the research scientists, contact the Research Subjects' Advocate Line, D528 Mayo, 420 Delaware Street SE, Minneapolis, MN 55455. Phone: 612-625-1650.

Statement of Consent: I have read the above information and asked any questions that I had. I consent to participate in the study. I have been given a copy of the consent form.

Signature____________________________________ Date ________________

Signature of Investigator ________________________ Date ________________

APPENDIX C

First Internet Survey: Questions

A survey site by Battelle

Contact Us

Forget your ID?

Help

Initial Driver Survey for Mn/DOT

If you have registered a login password previously, continue on to the survey...

If you are new to this site, please provide a login password you would like for use at this site (5 to 14 characters in length). Be certain to record this login password, so you may enter the site later and review your responses.

(Note: if your requested password is assigned to another user already, you will return to this page so you may request an alternate login password)

password

confirm password

Register

Battelle is the independent evaluator that is conducting this survey on behalf of the U.S. Department of Transportation to evaluate new safety technology systems that provide two primary capabilities that include:

1. Collision avoidance
2. Lane keeping

Please plan to answer these questions on your own, without first discussing them with others. We want your personal opinions, both pro and con, about these systems.

Battelle's ISIS

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Please **read** the information **below**.
When you are finished, you may hit the OK button to continue.

Battelle is the independent evaluator that is conducting this survey on behalf of the U.S. Department of Transportation to evaluate new safety technology systems that provide two primary capabilities that include:

1. Collision avoidance
2. Lane keeping

Please plan to answer these questions on your own, without first discussing them with others. We want your personal opinions, both pro and con, about these systems.

Your participation in this study is completely voluntary. All of the information you provide in this interview will be kept strictly confidential and will not be disclosed to anyone but the researchers conducting the study. Your employer will not be given your answers to these questions.

The survey should take about 10 minutes to complete. We plan to conduct several additional surveys between now and April 2002. In order to follow-up with you later, we need to have your name. Please provide your name as your first response in this survey.

OK

Battelle's
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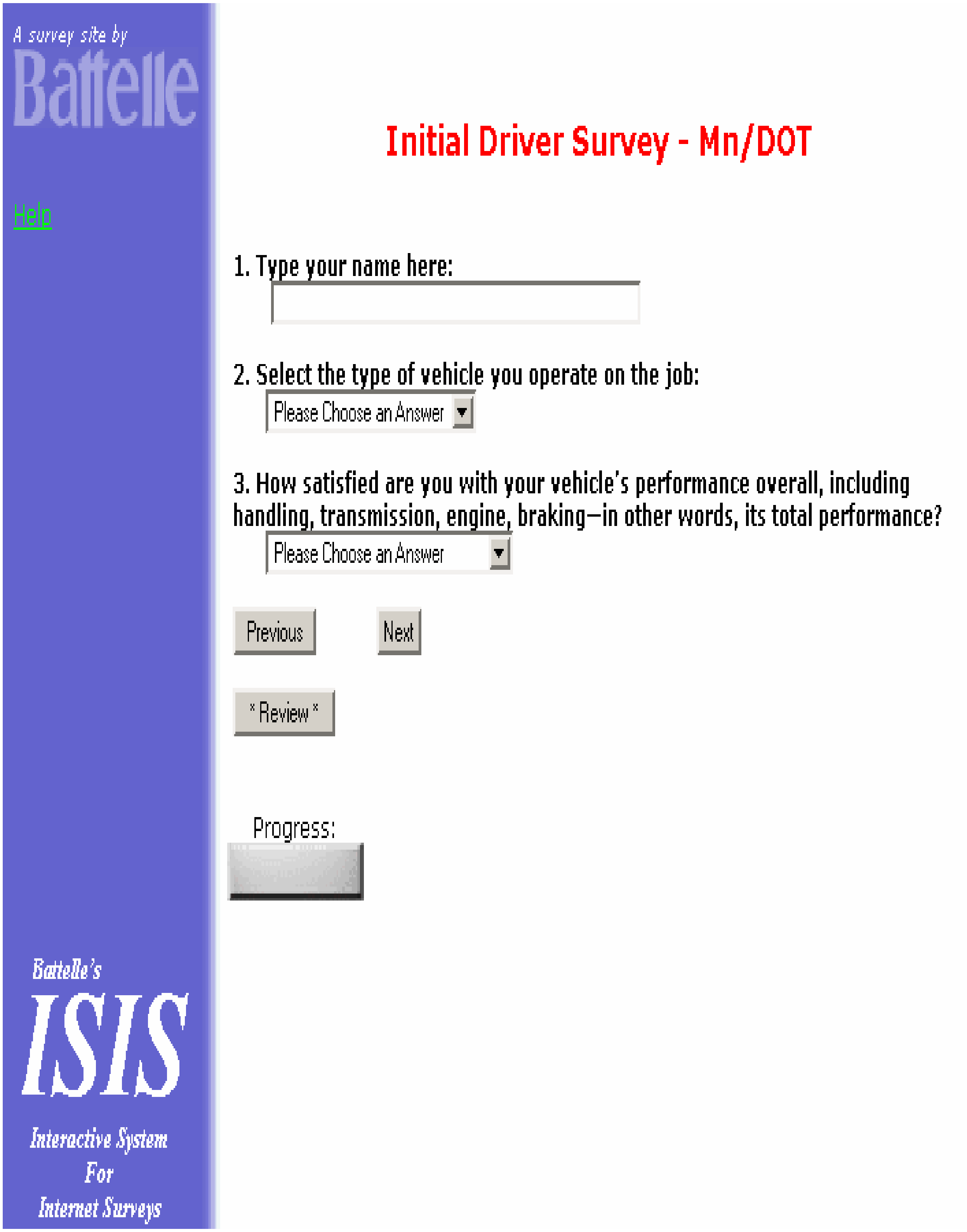
A survey site by
Battelle
Help
Initial Driver Survey - Mn/DOT
1. Type your name here:
2. Select the type of vehicle you operate on the job:
Please Choose an Answer
3. How satisfied are you with your vehicle's performance overall, including handling, transmission, engine, braking—in other words, its total performance?
Please Choose an Answer
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4. Up to now, how many times have you driven your vehicle with each of these four technologies operating properly in low visibility or difficult driving conditions, such as snow on the road, blowing snow, fog, rain, or night time?

	Choose one box for each of the 4 technologies.				
Front-looking radar	Never	1 time	2 times	3 times	4 or more times
Side-looking radar	Never	1 time	2 times	3 times	4 or more times
Heads Up Display	Never	1 time	2 times	3 times	4 or more times
Lane Departure Warning	Never	1 time	2 times	3 times	4 or more times

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Help

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5. In general, do you see these technology systems (collision avoidance and lane keeping) as likely to be:

- ○ Useful to you in driving your vehicle?
- ○ Creating problems for you when driving your vehicle?
- ○ Not useful to you but not a problem either in driving your vehicle?

6. Please think back over your driving experiences in low visibility or poor conditions. Estimate how often you have to take evasive maneuvers, such as braking hard, making sudden lane changes, or other actions, to avoid an accident because a vehicle pulled in front of you, stopped or slowed suddenly, or appeared suddenly in front of you?

Please Choose an Answer ▼

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7. The lane departure warning system has three parts, seat vibration, audible warning, and visual warning on the HUD. How useful do you think each of these three warning systems will be to you in indicating lane departure under marginal driving conditions?

	Choose one answer for each				
Seat vibration	Very Useful	Somewhat Useful	Uncertain (Neutral)	Not Very Useful	Not At All Useful
Audible warning	Very Useful	Somewhat Useful	Uncertain (Neutral)	Not Very Useful	Not At All Useful
Visual Warning	Very Useful	Somewhat Useful	Uncertain (Neutral)	Not Very Useful	Not At All Useful

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8. In the next set of questions, we are asking you to answer some questions about the collision avoidance system.

When answering each part of Question 8, consider the entire collision avoidance system, including forward and side radar, vehicle and roadside object display on the HUD, and warning lights, sounds and symbols

Statement	Choose one answer for each				
	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
8a. I am concerned that the collision avoidance system can interfere with my driving tasks.	○	○	○	○	○
8b. I expect it would be easy for me to learn how to use the collision avoidance system.	○	○	○	○	○
8c. I expect that my driving will **not** change as a result of having the collision avoidance system on my vehicle.	○	○	○	○	○
8d. I am concerned that the collision avoidance system increases the amount of effort it takes to drive a vehicle.	○	○	○	○	○
8e. I expect that the collision avoidance system would reduce the stress and fatigue of driving.	○	○	○	○	○
8f. I expect that the collision avoidance system would reduce the number of accidents or near-accident situations.	○	○	○	○	○

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Help

Initial Driver Survey - Mn/DOT

9. The second set of questions deals with the lane keeping system.

When answering each part of Question 9, consider the entire lane keeping system, including the GPS, 3M magnetic tape, the HUD, and warning lights, sounds, vibrations and symbols.

Statement	Choose one answer for each				
9a. I am concerned that the lane keeping system can interfere with my driving tasks.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
9b. I expect it would be easy for me to learn how to use the lane keeping system.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
9c. I expect that my driving will **not** change as a result of having the lane keeping system on my vehicle.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
9d. I am concerned that the lane keeping system increases the amount of effort it takes to drive a vehicle.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
9e. I expect that the lane keeping system would reduce the stress and fatigue of driving.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
9f. I expect that the lane keeping system would reduce the number of accidents or near-accident situations.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

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Help

Initial Driver Survey - Mn/DOT

The following questions are about high-tech systems in general.

Statement	Choose one answer for each				
10. High tech systems really do **not** help the experienced driver avoid front-end collisions.	Strongly Disagree ○	Disagree ○	Neither Agree nor Disagree ○	Agree ○	Strongly Agree ○
11. I would be better off driving without these types of high tech systems.	Strongly Disagree ○	Disagree ○	Neither Agree nor Disagree ○	Agree ○	Strongly Agree ○
12. These high tech vehicle safety systems create an added distraction in my vehicle.	Strongly Disagree ○	Disagree ○	Neither Agree nor Disagree ○	Agree ○	Strongly Agree ○

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"Mental workload" is the mental effort it takes for you to perform tasks. Think in terms of your level of concentration, amount of mental effort, or degree of mental focus.

On a mental workload scale of 0 to 10,

- *0 means no mental workload*
- *1 means very low mental workload*
- *10 means the highest mental workload.*

Please check a number between 0 and 10 that reflects your estimate of the level of mental workload under each of the following.

Statement	0 No mental workload	1	2	3	4	5	6	7	8	9	10 Highest mental workload
13. Normal driving conditions when you drive your own personal automobile?	○	○	○	○	○	○	○	○	○	○	○
14. When driving your (snowplow/ambulance/ patrol car) in average winter conditions with good visibility and **without** these new technologies?	○	○	○	○	○	○	○	○	○	○	○
15. When driving your (snowplow/ambulance/ patrol car) in the worst winter conditions with poor visibility and **without** these new technologies?	○	○	○	○	○	○	○	○	○	○	○
16. When driving your (snowplow/ ambulance/patrol car) in the worst winter conditions with poor visibility **with** these new technologies functioning properly?	○	○	○	○	○	○	○	○	○	○	○

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Initial Driver Survey - Mn/DOT

You can call John Scharffbillig at (612) 670-0594 if you have any questions about this technology program or Jessica Sanford at (614) 424-4998 if you have specific questions regarding this survey.

We will be conducting a second survey in about two months from now to discuss your driving experiences.

Thank you for your participation!

Write any comments below. Note question numbers to which your comment(s) may apply (if you need to refer to questions from earlier in the survey, you may find entering comments easier by hitting the review button):

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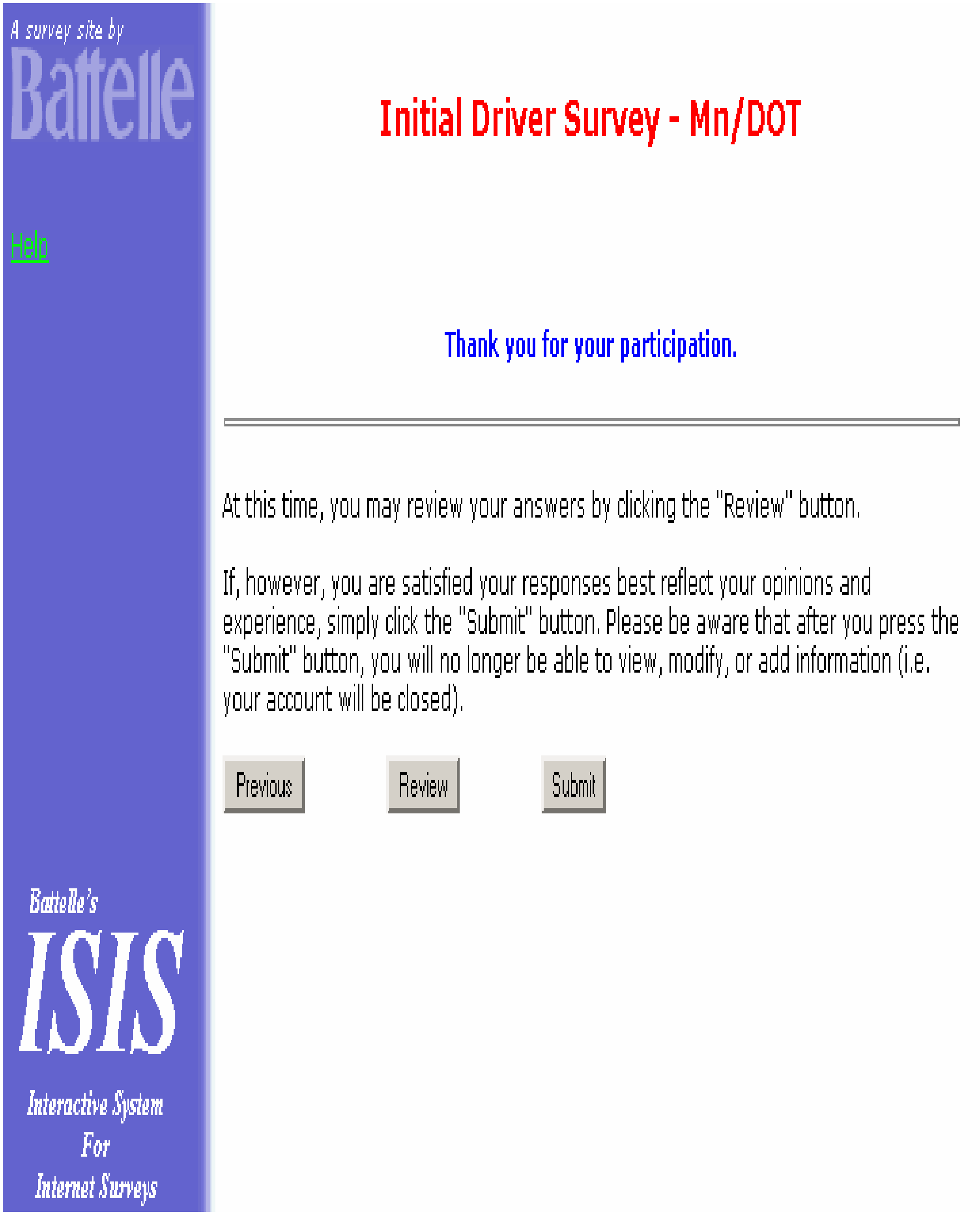
A survey site by
Battelle
Help
Initial Driver Survey - Mn/DOT
Thank you for your participation.
At this time, you may review your answers by clicking the "Review" button.
If, however, you are satisfied your responses best reflect your opinions and experience, simply click the "Submit" button. Please be aware that after you press the "Submit" button, you will no longer be able to view, modify, or add information (i.e. your account will be closed).
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Contact Information

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Initial Driver Survey - Mn/DOT

Thank You

This completes the survey process. Your responses have been saved. They will be used along with those submitted by this survey's other participants for analyzing and reporting aggregate findings.

Your survey has been successfully submitted.

(You may close this window manually now if you wish; otherwise, it will close automatically in 10 seconds.)

CONFIDENTIALITY: This information collection complies with the Federal Statistical Confidentiality Order. Therfore, by law, your responses may be used only for statistical purposes and may not be disclosed, or used, in identifiable form for any other purpose. Your survey instrument will be treated as confidential.

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APPENDIX D

Second Internet Survey: Questions

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Forget your ID?

Help

Final Internet Driver Survey for 2001-2002 Operations Mn/DOT

If you have registered a login password since April 1, 2002, continue on to the survey...

Beginning April 1, 2002, if you are logging in for the first time, please provide a login password you would like for use at this site (5 to 14 characters in length). You can use any password, including one you may have used previously at this site. Be certain to record this login password, so you may enter the site later and review your responses.

(Note: if your requested password is assigned to another user already, you will return to this page so you may request an alternate login password)

password

confirm password

Register

Battelle's ISIS

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Please **read** the information **below**.
When you are finished, you may hit the OK button to continue.

Battelle is the independent evaluator that is conducting this second and final Internet survey on behalf of the U.S. Department of Transportation to evaluate new safety technology systems that provide two primary capabilities that include:

1. Collision avoidance
2. Lane keeping

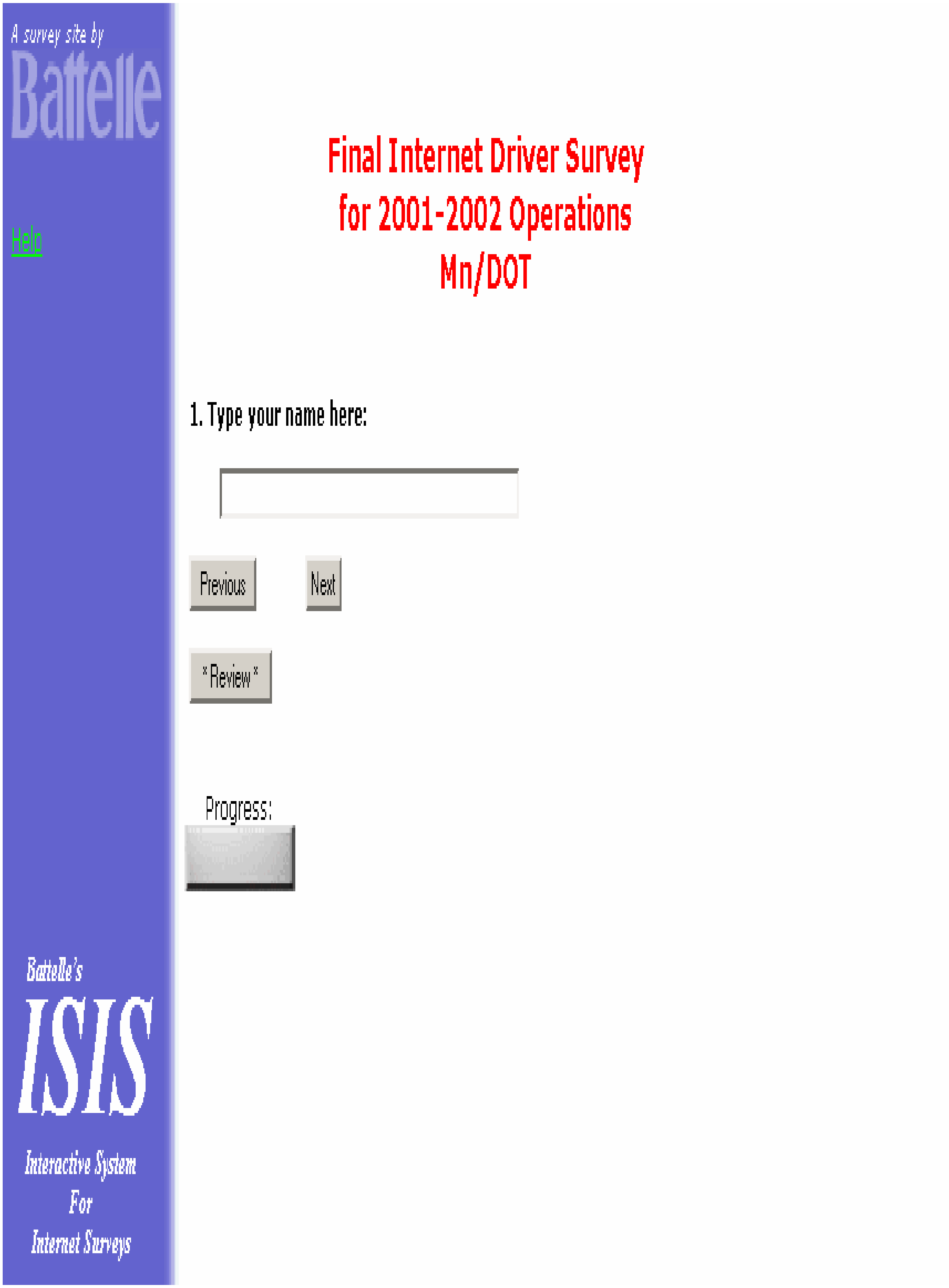
Please plan to answer these questions on your own, without first discussing them with others. We want your personal opinions, both pro and con, about these systems.

Your participation in this study is completely voluntary. All of the information you provide in this interview will be kept strictly confidential and will not be disclosed to anyone but the researchers conducting the study. Your employer will not be given your answers to these questions.

The survey should take about 10 minutes to complete. In order to follow-up with you later, we need to have your name. Please provide your name as your first response in this survey.

OK

Battelle's ISIS Interactive System For Internet Surveys


A survey site by
Battelle
Help
Final Internet Driver Survey
for 2001-2002 Operations
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1. Type your name here:
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2. Since January of this year, how many times have you driven your vehicle with each of these four technologies operating properly in low visibility or difficult driving conditions, such as snow on the road, blowing snow, fog, or heavy rain?

	Choose one box for each of the 4 technologies.				
	Never	1 time	2 times	3 times	4 or more times
Front-looking radar	◯	◯	◯	◯	◯
Side-looking radar	◯	◯	◯	◯	◯
Heads Up Display	◯	◯	◯	◯	◯
Lane Departure Warning	◯	◯	◯	◯	◯

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3. The lane departure warning system has three parts, seat vibration, audible warning, and visual warning on the HUD. How useful do you think each of these three warning systems has been to you in indicating lane departure under marginal driving conditions?

	Choose one answer for each				
Seat vibration	Very Useful ◯	Somewhat Useful ◯	Uncertain (Neutral) ◯	Not Very Useful ◯	Not At All Useful ◯
Audible warning	Very Useful ◯	Somewhat Useful ◯	Uncertain (Neutral) ◯	Not Very Useful ◯	Not At All Useful ◯
Visual warning	Very Useful ◯	Somewhat Useful ◯	Uncertain (Neutral) ◯	Not Very Useful ◯	Not At All Useful ◯

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4. Next, we would like you to answer some questions about the collision avoidance system.

When answering each part of Question 4, consider the entire collision avoidance system, including forward and side radar, vehicle and roadside object display on the HUD, and warning lights, sounds and symbols

Statement	Choose one answer for each
4a. The collision avoidance system interferes with my driving tasks.	Strongly Disagree / Disagree / Neither Agree nor Disagree / Agree / Strongly Agree
4b. It has been easy for me to learn how to use the collision avoidance system.	Strongly Disagree / Disagree / Neither Agree nor Disagree / Agree / Strongly Agree
4c. My driving has **not** changed as a result of having the collision avoidance system on my vehicle.	Strongly Disagree / Disagree / Neither Agree nor Disagree / Agree / Strongly Agree
4d. The collision avoidance system increases the amount of effort it takes to drive a vehicle.	Strongly Disagree / Disagree / Neither Agree nor Disagree / Agree / Strongly Agree

Statement	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
4e. The collision avoidance system reduces the stress and fatigue of driving.	○	○	○	○	○
4f. The collision avoidance system reduces the number of accidents or near-accident situations.	○	○	○	○	○
4g. The collision avoidance system is distracting to me in my driving.	○	○	○	○	○
4h. I would like the collision avoidance system to be kept and maintained on my vehicle in the future.	○	○	○	○	○

Please note here any specific comments, pro or con, about your experiences with the collision avoidance system:

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5. The second set of questions deals with the lane keeping system.

When answering each part of Question 5, consider the entire lane keeping system, including the GPS, 3M magnetic tape, the HUD, and warning lights, sounds, vibrations and symbols.

Statement	Choose one answer for each				
	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
5a. The lane keeping system interferes with my driving tasks.	◯	◯	◯	◯	◯
5b. It has been easy for me to learn how to use the lane keeping system.	◯	◯	◯	◯	◯
5c. My driving has **not** changed as a result of having the lane keeping system on my vehicle.	◯	◯	◯	◯	◯
5d. The lane keeping system increases the amount of effort it takes to drive a vehicle.	◯	◯	◯	◯	◯

5e. The lane keeping system reduces the stress and fatigue of driving.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
5f. The lane keeping system reduces the number of accidents or near-accident situations.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
5g. The lane keeping system is distracting to me in my driving.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
5h. I would like the lane keeping system to be kept and maintained on my vehicle in the future.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

Please note here any specific comments, pro or con, about your experiences with the lane keeping system:

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The following questions are about high-tech systems in general.

Statement	Choose one answer for each				
6. High tech systems really do **not** help the experienced driver avoid front-end collisions.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
7. I would be better off driving without these types of high tech systems.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
8. These high tech vehicle systems increase my safety while driving.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

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"Mental workload" is the mental effort it takes for you to perform tasks. Think in terms of your level of concentration, amount of mental effort, or degree of mental focus.

On a mental workload scale of 0 to 10,

- *0 means no mental workload*
- *1 means very low mental workload*
- *10 means the highest mental workload.*

Please check a number between 0 and 10 that reflects your estimate of the level of mental workload under each of the following.

Statement	Choose one answer										
	0 No mental workload	1	2	3	4	5	6	7	8	9	10 Highest mental workload
9. Normal driving conditions when you drive your own personal automobile?	○	○	○	○	○	○	○	○	○	○	○
10. When driving your (snowplow/ambulance/ patrol car) in average winter conditions with good visibility and **without** these new technologies?	○	○	○	○	○	○	○	○	○	○	○
11. When driving your (snowplow/ambulance/ patrol car) in the worst winter conditions with poor visibility and **without** these new technologies?	○	○	○	○	○	○	○	○	○	○	○
12. When driving your (snowplow/ ambulance/patrol car) in the worst winter conditions with poor visibility **with** these new technologies functioning properly?	○	○	○	○	○	○	○	○	○	○	○

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You can call John Scharffbillig at (612) 670-0594 if you have any questions about this technology program or Jessica Sanford at (614) 424-4998 if you have questions specific to this survey.

Thank you for your participation!

Write any comments below, including problems experienced with these systems or suggestions for improving them, or any other observations you care to provide. Note question numbers to which your comment(s) may apply (if you need to refer to questions from earlier in the survey, you may find entering comments easier by hitting the review button):

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Thank you for your participation.
At this time, you may review your answers by clicking the "Review" button.
If, however, you are satisfied your responses best reflect your opinions and experience, simply click the "Submit" button. Please be aware that after you press the "Submit" button, you will no longer be able to view, modify, or add information (i.e. your account will be closed).
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Thank You

This completes the survey process. Your responses have been saved. They will be used along with those submitted by this survey's other participants for analyzing and reporting aggregate findings.

Your survey has been successfully submitted.

(You may close this window manually now if you wish; otherwise, it will close automatically in 10 seconds.)

CONFIDENTIALITY: This information collection complies with the Federal Statistical Confidentiality Order. Therfore, by law, your responses may be used only for statistical purposes and may not be disclosed, or used, in identifiable form for any other purpose. Your survey instrument will be treated as confidential.

Battelle's ISIS

Interactive System For Internet Surveys

APPENDIX E

Ergonomics Assessment Checklist

DESCRIPTIVE PROFILE, HUMAN FACTORS ASSESSMENT, AND
OPERATIONAL JUDGEMENTS OF THE DRIVER/SYSTEM INTERFACE

Date: _____ / _____ / _____ Type of System: _____ ______________________

Product(s) Name(s): ____

____

____

____

Manufacturer
Name and Address: ____

____

____

Test Vehicle: ____
(make, model, year)

Completed by: ____

Position: ____

Previous experience
with this device: ____

DESCRIPTIVE PROFILE, HUMAN FACTORS ASSESSMENT, AND OPERATIONAL PERFORMANCE JUDGEMENTS OF THE DRIVER/SYSTEM INTERFACE

The purpose of this document is to serve as a tool for the collection of data regarding systems and their associated visual and auditory information displays. In addition, this document composes both a research device and screening tool by which the merits of systems may be assessed. The information collected includes: 1) descriptions of the operation of the system hardware and displays; 2) an assessment of the extent to which the visual and auditory displays conform to established human factors guidelines; and 3) an assessment of operational performance of the driver/system interface. This information may be used to evaluate the effectiveness of the driver/system interface.

The term, 'crash avoidance warning', used throughout this document, refers to any information which a system provides to the driver to help prevent an accident. The type of information this warning consists of is dependent on the category of a particular system. Crash avoidance warnings are divided into two categories here: 1) and 2) imminent. ______________________warning information is any information provided by a system which warns the driver of a potentially dangerous situation (i.e., obstructing vehicle in an adjacent lane when considering changing lanes, obstructing vehicle to the rear when backing). ______________________warning information refers to any information which a system might provide to warn the driver of an impending collision.

SECTION A: DESCRIPTIVE PROFILE

The purpose of the descriptive profile of the system is to record information regarding the system's operation, sensor configuration, and physical characteristics of the visual and auditory driver displays. These data may be used to evaluate the appropriateness of the display characteristics and the effectiveness of the driver/system interface. This section is to be completed by a human factors expert.

SECTION B: HUMAN FACTORS ASSESSMENT

The purpose of the human factors assessment is to determine the extent to which the design of a particular system's driver/system interface conforms to accepted human factors design principles. These data may be used as stand-alone evaluations or a means for relative comparison among systems. This section is to be completed by one or more human factors experts.

SECTION C: OPERATIONAL JUDGEMENTS OF THE DRIVER/SYSTEM INTERFACE

This section is intended to be subjective assessment of the driver/system interface. Individuals completing this section should include one or more human factors experts per system, if possible. Experts will review the manufacturer's documentation and become familiar with the operation of the system through practice with the device before completing Part I of this section. They will then operate a test vehicle over a fixed route in traffic with an operational system installed in the vehicle. Part II should be filled out after the test drive has been completed. These subjective data form an assessment of the driver/system interface from the user's point of view and provide a means for comparison of this subjective information with objective data collected in other stages of the system evaluation.

SECTION A

DESCRIPTIVE PROFILE OF SYSTEM AND DRIVER/SYSTEM INTERFACE

Instructions for Section A:

- This section is to be completed by a human factors expert.

- Measurements should be taken in a laboratory setting if possible.

- Metric units should be used.

- A detailed 20.32 X 25.4 cm (8 X 10 inch) photograph with ruler in the frame should be taken as part of this data collection effort.

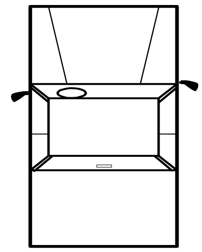
- Suggested references and sources of criteria for use in assessing the appropriateness of the driver/system interface features and the overall effectiveness of this interface include any SAE Recommended Practice. In the event that specific recommendations for some aspect of the interface cannot be found in any SAE recommendation, other sources of human factors design principles, such as 'Preliminary Human Factors Guidelines for ______________________warning Devices' (COMSIS, 1993), the 'Human Factors Design Handbook' (Woodson, 1992), the 'Handbook of Human Factors' (Salvendy, 1987), MIL-STD-1472, or other preferred text, may be used. When referencing specific texts, the evaluator should give a full reference (including page number) for the information cited.

Part I General Information

1. Brief system description:

   a. What type of sensor technology (e.g., ultrasonic, position radar, etc.) does the system use?

   b. How many sensors are used with the system and what areas of coverage are associated with each? Use the given picture to illustrate the detection zone(s) around the vehicle.



c. What is the effective (or nominal) range of the sensors as stated in the manufacturer□s specifications?

2. In Table I below, list the manufacturer's suggested mounting location for each visual display (and auditory warning unit or control, if separately mounted). Write 'Not Specified' if the manufacturer does not specify mounting locations.

3. In Table I below, list the overall dimensions (width x height x depth) of each display and control unit. **Use millimeters** (round to nearest millimeter).

TABLE I
Mounting Locations and Overall Dimensions

Display, Auditory Message or Control	Manufacturer's Recommended Mounting Location	Overall Dimensions (For reference) (W x H x D)
System status display	____________________	__________ mm
crash avoidance warning	____________________	__________ mm
crash avoidance warning	____________________	__________ mm
Other ______________ (specify)	____________________	__________ mm
Other ______________ (specify)	____________________	__________ mm

Note: Although most manufacturers may use a single integrated display, control and warning unit, the organization of Table I provides for multiple units, each separately mounted in different locations in the vehicle. If a single integrated display, control and warning unit is used, please note this information in Table I.

4. In Table II below, list the maximum viewing distance to each visual display unit with the system installed in the manufacturer's recommended location(s). Note that the maximum viewing distance for displays mounted in front of the driver is the distance from the seated eye position of the 95th percentile male driver to the center of the visual display. If the manufacturer does not specify a mounting location, assume a mounting location in or on top of the instrument panel within 15 degrees horizontally and vertically of the driver's normal straight-ahead line of sight to the road, and note that this default location is being used.

TABLE II
Maximum Display Viewing Distances

Display	Viewing Distance
Display ____________________	__________ mm
Display ____________________	__________ mm
Display ____________________	__________ mm
Display ____________________	__________ mm

5. In Table III below, list the maximum reach distance* to the control unit with the control unit installed in the manufacturer's recommended location(s). If the manufacturer does not specify a mounting location, assume a mounting location in or on top of the instrument panel within 15 degrees horizontally and vertically of the driver's normal straight-ahead line of sight to the road and use of this default location should be noted. For controls located in front of the driver, the 95th percentile male driver's seated position will determine the maximum reach distance to controls.

* The maximum reach distance is defined to be the straight line distance from the driver's shoulder to the control. The need for reaching around obstructions, such as the steering wheel, should be noted.

TABLE III
Maximum Control Reach Distances

Control Unit	Reach Distance
______________________________ (Specify)(e.g., warning volume)	__________ mm
______________________________ (Specify)	__________ mm
______________________________ (Specify)	__________ mm

6. In Table IV, for each item of information presented by the system, enter information in the appropriate columns.

7. In Table V below, list the auditory messages that are presented by the system. For each message, enter the information shown at the top of the columns.

   Notes for Table V

   a. Measure auditory characteristics of messages at the driver's seat with ignition switch off (i.e., engine and all accessories off) and windows up.

8. In Table VI below, for each control, enter the information listed at the top of the columns.

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TABLE IV
Descriptive Profile Visual Displays

(If no display is present for an item listed in the leftmost column, write N/A [not applicable] in the appropriate boxes.)

NAME OF DISPLAYED INFORMATION	TYPE OF INFORMATION DISPLAYED (i.e., distance to adjacent vehicle)	TRIGGERING EVENT	TYPE OF DISPLAY USED (LCD, LED, icon)	TYPE OF COLOR CODING USED
System on/off				
System malfunction				
Other (list)				
Other (list)				
Other (list)				
Other (list)				

TABLE IV
Descriptive Profile Visual Displays
(Continued)

(If no display is present for an item listed in the leftmost column, write N/A [not applicable] or '--' in the appropriate boxes.)

NAME OF DISPLAYED INFORMATION	DISPLAY LUMINANCE-DAY (min. & max. brightness setting)	DISPLAY LUMINANCE-Night (min. & max. brightness setting) if possible	DUTY CYCLE (steady burn, flash rate)	SIZE OF DISPLAYED INFORMATION (diameter, smallest character height and width, stroke width)	VISUAL ANGLE SUBTENDED AT MAXIMUM VIEWING DISTANCE (minutes of arc)
System on/off					
System malfunction					
Other (list)					
Other (list)					
Other (list)					
Other (list)					

TABLE V
Descriptive Profile Auditory Warnings

(If no display is present for an item listed in the leftmost column, write N/A [not applicable] in the appropriate boxes.)

NAME OF AUDITORY INFORMATION	TYPE OF INFORMATION PRESENTED	TRIGGERING EVENT	TYPE OF WARNING (steady, warble, intermittent)	PITCH (frequencies)	LOUDNESS (min. & max. loudness settings)	DURATION OF AUDIBLE WARNING SIGNAL	DUTY CYCLE (if intermittent)	CHANGES AFTER ONSET
System on								
System malfunction								
Other (list)								
Other (list)								
Other (list)								
Other (list)								

TABLE VI
Descriptive Profile Manual Controls

(If no display is present for an item listed in the leftmost column, write N/A [not applicable] in the appropriate boxes.)

CONTROL FUNCTION	CONTROL TYPE (knob, toggle, push button, etc.)	CONTROL SIZE (width X height, diameter, length, etc.)(in mm.)	DOES THE CONTROL OBSTRUCT THE DRIVER'S VIEW OF VISUAL WARNING DISPLAYS	TYPE OF ADJUSTMENT (discrete or continuous)	DESCRIBE TYPE OF CONTROL FEEDBACK (aural, visual, tactile)
System on/off					
Volume adjustment					
Light intensity (dimming) adjustment					
Sensor sensitivity adjustment					
Visual display override					
Audible display override					
Other (list)					
Other (list)					

Part II. Checklist of System Features
(All possible features may not be listed here. List other features at the bottom of the page.)

	Circle the word which best describes your response.	ND= Not determinable N/A= Not Applicable			
1	Does the system have a "self-test" feature that allows the driver to check for proper operation of visual displays, auditory warnings and logic circuits?	ND	No	Yes	N/A
2	Does the system have an automatic indicator of sensor failure?	ND	No	Yes	N/A
3	Does the system have an automatic indicator of visual display failure?	ND	No	Yes	N/A
4	Does the system have an automatic indicator of auditory warning failure?	ND	No	Yes	N/A
5	Does the system turn on (i.e., powered up) automatically (e.g., when the ignition switch is turned on)?	ND	No	Yes	N/A
6	Is the system on and functioning (i.e., providing warnings) at all times when the vehicle is in motion?	ND	No	Yes	N/A
7	Is the standby mode of the system's ______________________warning features enabled by the ignition switch?	ND	No	Yes	N/A
8	Are the ______________________warning features of the system enabled by the turn signal (or enabled by reverse gear for backup systems)?	ND	No	Yes	N/A
9	Is there a volume adjustment for the audible warning(s) that can be operated by the driver while driving?	ND	No	Yes	N/A
10	Is there a display brightness adjustment for the visual displays that can be operated by the driver while driving?	ND	No	Yes	N/A
11	Does the system adjust the brightness of the visual display automatically?	ND	No	Yes	N/A
12	Does the system use both visual and auditory presentation of ______________________warning information?	ND	No	Yes	N/A
13	Is there a sensor sensitivity adjustment control present that can be adjusted by the driver while the vehicle is in motion?	ND	No	Yes	N/A
14	Is there a manual override for the visual and auditory signals for instances when objects known to the driver are encountered in the blind spot?	ND	No	Yes	N/A
15	Are any visual displays present (i.e., actively presenting information) on the device when there are NO objects sensed in the detection zone?	ND	No	Yes	N/A

SECTION B

HUMAN FACTORS ASSESSMENT OF DRIVER/SYSTEM INTERFACE

(In the material to follow, the term, "appropriate", means compliance with accepted SAE Recommended Practices and/or human factors design principles)

Instructions for Section B:

- This section is to be completed by one or more human factors experts.

- The individual completing this section should be familiar with the referenced SAE Recommended Practices and human factors guidelines before beginning this section.

- Measurements made in Section A may be used in determining the appropriateness of design characteristics.

- Suggested references and sources of criteria for use in assessing the appropriateness of the driver/system interface features and the overall effectiveness of this interface include any SAE Recommended Practice. In the event that specific recommendations for some aspect of the interface cannot be found in any SAE recommendation, other sources of human factors design principles, such as 'Preliminary Human Factors Guidelines for ______________________warning Devices' (COMSIS, 1993), the 'Human Factors Design Handbook' (Woodson, 1992), the 'Handbook of Human Factors' (Salvendy, 1987), MIL-STD-1472, or other preferred text, may be used. When referencing specific texts, the evaluator should give a full reference (including page number) for the information cited.

Part I. _____________________Warning Visual Displays

Circle the number or word which best describes your response.
Note: Fill out a separate table for each different visual display if necessary.

	Circle the word which best describes your response.	ND= Not determinable N/A= Not Applicable
1	Is displayed _________________warning information labeled?	ND No Yes N/A
2	Are the information coding methods used (e.g., size, shape, brightness, color) for _____________________warning appropriate for the type of information presented?	ND No Yes N/A
3	Do the information coding techniques used for crash avoidance warnings conform to population stereotypes (e.g., brighter or larger displayed information for traffic closer to the driver)?	ND No Yes N/A
4	Is _____________________warning information presented using appropriate redundant visual codes (e.g., simultaneous brightness and size increases as traffic gets closer)?	ND No Yes N/A
5	Does the organization of _____________________warning information facilitate quick acquisition of information while driving?	ND No Yes N/A
6	Are the _____________________warning visual displays located within 15 degrees horizontally and vertically of the driver's line of sight to the right side mirrors? (for right side systems)	ND No Yes N/A
7	Are the _____________________warning visual displays located within 15 degrees horizontally and vertically of the driver's line of sight to the left side mirrors? (for left side systems)	ND No Yes N/A
8	Are the _____________________warning visual displays located within 15 degrees horizontally and vertically of the driver's straight-ahead line of sight to the road?	ND No Yes N/A
9	Is the presence of the _____________________warning visual signal noticeable when the driver looks at the right side view mirrors?	ND No Yes N/A
10	Is the presence of the _____________________warning visual signal noticeable when the driver looks at the left side view mirrors?	ND No Yes N/A
11	Is the presence of the _____________________warning visual signal noticeable when the driver looks at the inside rear view mirror?	ND No Yes N/A
12	Is the presence of the _____________________warning visual signal noticeable when the driver looks straight ahead?	ND No Yes N/A
13	Is the presence of the _____________________warning visual signal noticeable when the driver looks midway between the right side A and B pillars?	ND No Yes N/A
14	Is the driver's line of sight to the _____________________warning visual displays unobstructed (e.g., by other controls, displays or vehicle components)?	ND No Yes N/A
15	Can the driver discriminate the _____________________warning from any other proximally displayed information (e.g., system status information)?	ND No Yes N/A
16	Are the _____________________warning displays legible in daylight?	ND No Yes N/A
17	Are the _____________________warning displays legible in darkness?	ND No Yes N/A
18	Are the _____________________warning displays legible in light from specular glare sources (e.g., overhead street lights, sun)?	ND No Yes N/A
19	How effectively have SAE Recommended Practices and human factors design principles been applied to the design of the _____________________warning visual displays?	Very Ineffectively major changes needed / Somewhat Effectively some changes needed / Very Effectively few changes needed ND 1 2 3 4 5 N/A
20	How effectively have the _____________________warning visual display(s) been designed to help drivers make right lane changes without collision?	ND 1 2 3 4 5 N/A

	Circle the word which best describes your response.	ND= Not determinable N/A= Not Applicable
21	How effectively have the _____________________warning visual display(s) been designed to help drivers make left lane changes without collision?	ND 1 2 3 4 5 N/A
22	How effectively have the _____________________warning visual display(s) been designed to help drivers make right merges without collision?	ND 1 2 3 4 5 N/A
23	How effectively have the _____________________warning visual display(s) been designed to help drivers make left merges without collision?	ND 1 2 3 4 5 N/A
24	How effectively have the _____________________warning visual display(s) been designed to assist drivers in backing without collision?	ND 1 2 3 4 5 N/A

Part II. ____________________ Warnings - Auditory

Circle the number or word that best describes your response.
Note: Fill out a separate table for each different auditory display if necessary.

	Circle the word which best describes your response.	ND= Not determinable N/A= Not Applicable
1	Is the lowest volume setting at least 60 dBA?	ND No Yes N/A
2	Is the highest volume setting not more than 90 dBA?	ND No Yes N/A
3	Is the frequency (i.e., tone) of auditory warnings between 500 and 3000 Hz?	ND No Yes N/A
4	Are complex tones (vs. pure tones) used for auditory warnings?	ND No Yes N/A
5	Are the meanings of the auditory warnings easy for the driver to understand?	ND No Yes N/A
6	How many of levels of auditory warnings are used?	ND No Yes N/A
7	Are the coding methods (e.g., "beep rate", tonal changes or loudness changes) appropriate for the type of warning presented?	ND No Yes N/A
8	Do coding methods used for _____________________warning conform to population stereotypes (e.g., higher pitched or faster beeping) for traffic closer to the vehicle?	ND No Yes N/A
9	Can the driver discriminate among the levels of coding used for the crash avoidance warnings (e.g., not more than four discrete levels of loudness)?	ND No Yes N/A
10	Can the driver discriminate the _____________________warning from other in-vehicle auditory warnings?	ND No Yes N/A
11	How effectively have SAE Recommended Practices and human factors design principles been applied to the design of _____________________warning auditory displays?	Very Ineffectively / Somewhat Effectively / Very Effectively **major changes needed** / **some changes needed** / **few changes needed** ND 1 2 3 4 5 N/A
12	Are the coding methods (e.g., "beep rate", tonal or loudness changes) appropriate for the type of _____________________warning presented?	ND No Yes N/A
13	Do coding methods used for crash avoidance warnings conform to population stereotypes (e.g., higher pitched or faster beeping) for traffic closer to the vehicle?	ND No Yes N/A
14	Can the driver discriminate the _____________________warning from other in-vehicle auditory warnings?	ND No Yes N/A
15	How effectively have SAE Recommended Practices and human factors design principles been applied to the design of	Very Ineffectively major changes / Somewhat Effectively some changes / Very Effectively few changes

	_______________________warning auditory displays?	needed needed needed ND 1 2 3 4 5 N/A
16	How effectively have the auditory _______________________warnings been designed to help drivers make right lane changes without collision?	ND 1 2 3 4 5 N/A
17	How effectively have the auditory _______________________warning display(s) been designed to help drivers make left lane changes without collision?	ND 1 2 3 4 5 N/A
18	How effectively have the auditory _______________________warning display(s) been designed to help drivers make right merges without collision?	ND 1 2 3 4 5 N/A
19	How effectively have the auditory _______________________warning display(s) been designed to help drivers make left merges without collision?	ND 1 2 3 4 5 N/A
20	How effectively have the auditory _______________________warning display(s) been designed to assist drivers in backing without collision?	ND 1 2 3 4 5 N/A

Part III. Auxiliary Information: System Status Displays

A. <u>System Status - Visual:</u> (e.g., on/off, display brightness, alarm intensity, system failure status and sensor sensitivity)
Note: Fill out a separate table for each different visual system status display if necessary.

	Circle the word which best describes your response.	**ND= Not determinable N/A= Not Applicable**
1	Can the driver discriminate from the display whether the system is on or off (i.e., powered or unpowered)?	ND No Yes N/A
2	Does the display present the setting status of driver adjustable parameters (e.g., brightness, volume controls, alarm intensity)?	ND No Yes N/A
3	Is displayed system status information labeled?	ND No Yes N/A
4	Are the status displays legible in daylight?	ND No Yes N/A
5	Are the status displays legible in darkness?	ND No Yes N/A
6	Are the status displays legible in light from specular glare sources (e.g., overhead street lights, sun)?	ND No Yes N/A
7	Are the information coding methods used for system status information (e.g., green for okay) appropriate for the type of information presented (when variable levels exist)?	ND No Yes N/A
8	Do the information coding techniques used conform to population stereotypes (e.g., red for a malfunction indicator)?	ND No Yes N/A
9	Are appropriate levels of coding used to present system status information to facilitate ease of discrimination among levels?	ND No Yes N/A
10	Does the organization of system status information facilitate quick acquisition of information presented while driving?	ND No Yes N/A
11	Can system status information be sufficiently discriminated from any other visual displays in the device?	ND No Yes N/A

B. System Status - Auditory (If relevant.)
Note: Fill out a separate table for each different auditory system status display if necessary.

	Circle the word which best describes your response.	ND= Not determinable N/A= Not Applicable
12	Is an auditory signal used to present system status information?	ND No Yes N/A
13	Are the coding methods (e.g., "beep rate", tonal changes or loudness changes) appropriate for the type of status information presented?	ND No Yes N/A
14	Do coding methods for status auditory warnings conform to population stereotypes?	ND No Yes N/A
15	Are multiple levels of coding auditory status information used?	ND No Yes N/A
16	Can the driver discriminate among the levels of coding used (e.g., not more than four discrete levels of loudness)?	ND No Yes N/A
17	Can the driver discriminate system status information from other in vehicle auditory warnings?	ND No Yes N/A

Part IV. Auxiliary Information: Manual Controls

Circle the number or word which best describes your response.
Note: Fill out a separate table for each manual control if necessary

	Circle the word which best describes your response.	ND= Not determinable N/A= Not Applicable
1	Does the driver have an unobstructed view of the controls from the forward driving position?	ND No Yes N/A
2	Are all controls labeled?	ND No Yes N/A
3	Are controls coded (size, shape, location, activation movement) for discrimination in blind operation?	ND No Yes N/A
4	Are controls separated to prevent accidental activation of controls adjacent to the one intended by the driver?	ND No Yes N/A
5	Does movement of all controls conform to population stereotypes (e.g., upward, right or clockwise movement to produce an increase in the value of a parameter)?	ND No Yes N/A
6	Does control use provide visual feedback?	ND No Yes N/A
7	Does control use provide tactile feedback? (e.g., detents, position, displacement)	ND No Yes N/A
8	Does control use provide auditory feedback (e.g., "clicks" or a volume change)?	ND No Yes N/A
9	Are control legends illuminated for viewing under nighttime driving conditions?	ND No Yes N/A
10	Are control legends legible in bright sunlight?	ND No Yes N/A
11	Are controls located such that the driver does not have to assume an awkward posture to operate the controls?	ND No Yes N/A
12	Is the appropriate control used for the type of function to be controlled? (e.g., avoiding toggle switches for volume control)	ND No Yes N/A
13	Do the controls provide their setting status on visual or tactile inspection?	ND No Yes N/A

Part V. Auxiliary Information: Legends

Circle the number or word which best describes your response. **Note: Fill out a separate table for each different visual display if necessary.**

	Circle the word which best describes your response.	**ND= Not determinable N/A= Not Applicable**
1	Are legends present on the driver/system interface?	ND No Yes N/A
2	Does the driver have an unobstructed view of each legend?	ND No Yes N/A
3	Are the legends legible in daylight?	ND No Yes N/A
4	Are the legends legible in darkness?	ND No Yes N/A
5	Are the legends legible in light from specular glare sources (e.g., overhead street lights, sun)?	ND No Yes N/A
6	Are legends located in acceptable positions on the device with respect to their associated control or display?	ND No Yes N/A
7	Are functional legends easily discriminated from advertising legends?	ND No Yes N/A

Part VI. Auxiliary Information: Documentation

For purposes of this section of the evaluation, the term documentation refers to material provided by the device manufacturer that describes system installation, calibration, operation and maintenance. This material could be distributed on a variety of media, including printed manuals, video tapes, audio tapes or CD ROM.

Type of documentation: Brochure Audio Tape Manual Video Tape Other _____________
(circle all that apply)

General

Circle the number or word which best describes your response.

	Circle the word which best describes your response.	**ND= Not determinable N/A= Not Applicable**
1	Does the documentation identify the device as supplemental to normal driver visual sampling of mirrors, etc.?	ND No Yes N/A
2	Does the documentation identify conditions under which system performance is degraded?	ND No Yes N/A
3	Does the documentation describe how to operate the system?	ND No Yes N/A
4	Does the documentation describe mounting locations for display(s), audible warning devices and controls?	ND No Yes N/A
5	Does the documentation describe installation procedures?	ND No Yes N/A
6	Does the documentation describe calibration procedures?	ND No Yes N/A
7	Does the documentation describe maintenance procedures?	ND No Yes N/A
8	Does the documentation give "trouble shooting" tips for common problems?	ND No Yes N/A
9	In summary, considering the control, display, warning, legend and discrimination issues presented above, how effectively has this system been designed from a human factors perspective?	Very Ineffectively major changes needed / Somewhat Effectively some changes needed / Very Effectively few changes needed ND 1 2 3 4 5 N/A

SECTION C

OPERATIONAL JUDGEMENTS OF THE DRIVER/SYSTEM INTERFACE

Name:______________________ Test Vehicle:

System:______________________ Date:_________________ Day / Night ?

Amount of driving experience with this system:

This section is to be completed by one or more human factors experts. It is desirable to have multiple human factors experts complete this section to allow for comparison and consolidation of responses. The test route will contain approximately 45 minutes of each of the following road types: arterial, highway, and rural highway. This route will be driven in the morning, in daylight conditions and not during rush hour. The same (or an equivalent) route should be driven under darkened nighttime conditions.

<u>Instructions for Section C:</u>

-Before beginning this section, the human factors expert should be provided with the manufacturer's instructions for use of the system and become familiar with the operation of the system through practice with the device.

- **Part I** should be completed first (before the human factors expert drives with the system). Part I is to be filled out in the test vehicle with the engine running.

- After completing Part I, the human factors expert will operate the test vehicle with an operational system installed in the vehicle over a fixed route in traffic and traversing the Columbus, Ohio area and containing approximately equal amounts of time spent on arterial, highway, and rural highway.

- **Part II** is to be completed after the human factors expert has completed driving with the system over the test route. This section should be completed while the subject is still seated in the test vehicle. This part of section C may be repeated after driving the route under nighttime conditions to collect data on interface effectiveness in a darkened environment.

- **Part III** consists of a qualitative summary in which the human factors expert records information regarding their experience with the system after having just driven with it. This section should be completed while the human factors expert is still in the test vehicle.

- Suggested references and sources of criteria for use in assessing the appropriateness of the driver/system interface features and the overall effectiveness of this interface include any SAE Recommended Practice. In the event that specific recommendations for some aspect of the interface cannot be found in any SAE recommendation, other sources of human factors design principles, such as 'Preliminary Human Factors Guidelines for ____________________warning Devices' (COMSIS, 1993), the 'Human Factors Design Handbook' (Woodson, 1992), the 'Handbook of Human Factors' (Salvendy, 1987), MIL-STD-1472, or other preferred text, may be used. When referencing specific texts, the evaluator should give a full reference (including page number) for the information cited.

<u>Note:</u> For the purposes of this document, please note the following definitions:

Distract - (*v.t.*) to draw away or divert, as the mind or attention.

Annoy - (*v.t.*) to disturb (a person) in a way that displeases, troubles, or slightly irritates.

Part I. Static Evaluation

Circle the number or word which best describes your response.

ND= Not Determinable
N/A= Not Applicable

Question	Rating
	Not At All Clear ... Very Clear
1. How clearly does the documentation tell you. . .	
a. The purpose of the system	ND 1 2 3 4 5 N/A
b. How to turn on/off the system	ND 1 2 3 4 5 N/A
c. How to operate and use the system	ND 1 2 3 4 5 N/A
2. Was there any information regarding the use of the system which you needed, but was not included in the documentation?	
	Not At All Readable ... Very Readable
3. How readable (legible) is the ______________________ warning display?	ND 1 2 3 4 5 N/A
	Very Ineffective ... Very Effective
4. How effective is the 'system test' feature for understanding the status of:	ND 1 2 3 4 5 N/A
a. The ______________________ warning visual displays?	ND 1 2 3 4 5 N/A
b. The auditory _______________ warnings?	
	Very Difficult ... Very Easy
5. How easy to understand are the meanings of	ND 1 2 3 4 5 N/A
a. The system status information visual displays?	ND 1 2 3 4 5 N/A
b. The system status auditory displays?	ND 1 2 3 4 5 N/A
c. The ______________________ warning visual displays?	ND 1 2 3 4 5 N/A
d. The ______________________ warning visual displays?	ND 1 2 3 4 5 N/A
e. The ______________________ warning auditory displays?	ND 1 2 3 4 5 N/A
f. The ______________________ warning auditory displays?	

Part II. Dynamic Evaluation (conducted after road test with system)

**** DRIVING SUMMARY ****

The human factors expert shall record the following items about the test run:

System Tested: ___________________________________ Test Vehicle:

Start Time: _____________ End Time: ______________ Duration: ______________

Circle as appropriate:

Traffic Conditions: Light Moderate Heavy

Ambient Light: Day (Specifiy: gloomy, moderate sunlight, bright sunlight) Night

Driving conditions: Dry Road Wet Road Rain Snow

Mirror Configuration on Test Vehicle (describe): Was the mirror system adequate?

____

1. While driving, how readable were the following visual displays: (If the displays contained text)

		Not At All Readable				Very Readable	
a. System status display(s)?	ND	1	2	3	4	5	N/A
b. _____________________warning display(s)?	ND	1	2	3	4	5	N/A

2. While driving, how well could system status information be discriminated from any other nearby displays in the device?

very difficult to discriminate				very easy to to discriminate	
ND	1	2	3	4	5	N/A

3. While driving, how well could _____________________warning displays be discriminated from any other nearby displays in the device?

very difficult to discriminate				very easy to to discriminate	
ND	1	2	3	4	5	N/A

4. While driving, how distracting were the following visual displays:

	very distracting					Not at all distracting	
a. System status display(s)?	ND	1	2	3	4	5	N/A
b. _____________________warning display(s)?	ND	1	2	3	4	5	N/A
c. _____________________warning display(s)?	ND	1	2	3	4	5	N/A

5. While driving, how distracting were the following auditory displays:

a. System status display(s)? ND 1 2 3 4 5 N/A

b. ____________________warning display(s)? ND 1 2 3 4 5 N/A

c. ____________________warning display(s)? ND 1 2 3 4 5 N/A

6. While driving, how annoying were the following auditory displays:

a. System status display(s)? ND 1 2 3 4 5 N/A

b. ____________________warning display(s)? ND 1 2 3 4 5 N/A

c. ____________________warning display(s)? ND 1 2 3 4 5 N/A

7. How would you describe the loudness of the auditory warnings compared to what you would expect for a warning system like this? ND Too Low OK Too High

8. How would you describe the pitch (tone) of the auditory warnings compared to what you would expect for a warning system like this? ND Too Low OK Too High

9. How effective was the visual ____________________warning presentation in helping you to make... (Not At All Effective … Very Effective)

a. right lane changes (for right side systems)? ND 1 2 3 4 5 N/A

b. left lane changes (for left side systems)? ND 1 2 3 4 5 N/A

10. How effective was the visual ____________________warning presentation in helping you to merge... (Not At All Effective … Very Effective)

a. to the right (for right side systems)? ND 1 2 3 4 5 N/A

b. to the left (for left side systems)? ND 1 2 3 4 5 N/A

11. How effective was the visual ____________________warning presentation in helping you perform backing maneuvers (for backing systems)? (Not At All Effective … Very Effective) ND 1 2 3 4 5 N/A

12. How effective was the auditory ____________________warning in helping you to make... (Not At All Effective … Very Effective)

a. right lane changes (for right side systems)? ND 1 2 3 4 5 N/A

b. left lane changes (for left side systems)? ND 1 2 3 4 5 N/A

13. How effective was the auditory ____________________warning presentation in helping you to merge... (Not At All Effective … Very Effective)

a. to the right (for right systems)? ND 1 2 3 4 5 N/A

b. to the left (for left side systems)? ND 1 2 3 4 5 N/A

14. Did you use the (side) ____________________warning information presented by the system to make a decision about a lane change?

    About what percent of all lane changes?

15. Did you use the ____________________warning information presented make a decision about merging (for side systems)?

    About what percent of all merges?

    ND No Yes N/A

16. Did you use the ____________________warning information presented by the system to make a decision about a backing maneuver (for backing systems)?

    About what percent of all backing maneuvers?

    ND No Yes N/A

17. Before you made a lane change or merging maneuver, did the crash avoidance warning information presented by the system cause you to use your mirrors more, less or about the same as you normally do?

    a. Left side mirror (for left side systems)

    ND Less Same More N/A

    b. Right side mirror (for right side systems)

    ND Less Same More N/A

    c. Rear view mirror (for rear systems)

    ND Less Same More N/A

18. When changing lanes or merging, did the ____________________warning information presented by the system cause you to look out the side windows more, less or about the same as you normally do?

    a. Left side (for left side systems) — ND Less Same More N/A

    b. Right side (for right side systems) — ND Less Same More N/A

19. Before you made a backing maneuver, did the rear crash avoidance warning information presented by the system cause you to use your mirrors more, less or about the same as you normally do?

    a. Left side mirror — ND Less Same More N/A

    b. Right side mirror — ND Less Same More N/A

    c. Rear view mirror — ND Less Same More N/A

20. When backing, did the rear ____________________warning information presented by the system cause you to look out the side windows more, less or about the same as you normally do?

    a. Left side — ND Less Same More N/A

    b. Right side — ND Less Same More N/A

Part III. Qualitative Driving Summary

1. How much time and effort did it take to get used to the system and become familiar with the operation of its interface?

2. What problems, if any, did you have in using the system interface? [List]

3. Of the problems identified above, which ones were the biggest problems for you and why?

4. Was the crash avoidance information presented by the system sufficiently noticeable when driving?

5. Was the crash avoidance information presented by the system easy to understand and useful?

6. Was the format in which the crash avoidance information was presented appropriate?

7. Did you experience any problems with glare (during the day due to sun, or at night) or other factor which hindered your perception of information presented by the system?

8. To what extent did you make (or almost make) an error of judgement when using the system? Explain.

9. To what extent was the presence of the system (driver/system interface) a distraction while driving (What aspects of the driver/system interface were distracting)? Why?

10. Did you find any part of the driver/system interface to be annoying while driving? What was annoying and why?

11. Did you visually sample the display when not making a lane change (for lane change/merge systems) or backing maneuver (for backup systems)?

12. Overall, how effectively has this system's interface been designed to help drivers make lane changes? Merges? Backing maneuvers?

13. If you could talk to the engineer who designed this system, what changes would you recommend to improve the **driver/system interface**?

14. If you could talk to the engineer who designed this system, what changes would you recommend to improve the **overall operation of the system**?

15. Would you be willing to buy this system (as tested) for your vehicle (car, truck)? Why or why not?

APPENDIX F

Proposed Research Options

RESEARCH OPTIONS

TEST PLANS FOR SUPPLEMENTAL/ALTERNATIVE EVALUATION STUDIES IN THE EVENT OF INSUFFICIENT LOW VISIBILITY WINTER WEATHER CONDITIONS DURING THE Mn/DOT IVI FIELD OPERATIONAL TEST

Submitted by the Battelle Evaluation Team
February 12, 2002

Introduction

The participants in the Mn/DOT IVI FOT have long recognized that a successful evaluation of the performance and benefits of Intelligent Vehicle Safety Systems (IVSS) for snowplows and other specialty vehicles depends upon ample winter weather conditions during the Field Operational Test (FOT) data collection period. Specific low-visibility winter weather conditions are needed in order to generate sufficient vehicle and driver performance data to achieve the goals and objectives of this evaluation in a statistically significant manner. While there are several types of weather conditions that fall into this category, a whiteout from blowing snow is the low-visibility condition of primary interest for evaluating the benefits of these IVSS vision-enhancement technologies.

Under normal weather patterns, it was anticipated that conducting the FOT during a single winter season in Minnesota would produce enough low-visibility weather conditions to result in the quantity of field operations data researchers needed to assess the performance of the IVSS in a comprehensive manner. However, with less than two months remaining in the six-month FOT period (October through March), the weather has not been ideal for achieving the FOT goals. Only scant operational data have been collected and none from operations during low visibility caused by blowing snow. Participants are now estimating that this winter season may not produce the conditions needed to adequately test the IVSS.

As the independent evaluator, Battelle prepared an evaluation plan that describes approaches to conducting (1) a comprehensive benefits analysis, with a primary focus on safety benefits; (2) an assessment of driver acceptance and human factors; (3) a limited analysis of system performance; (4) analyses of institutional and legal issues; and (5) an assessment of product maturity. Most of these planned analyses are affected by the availability of adequate weather conditions to generate appropriate evaluation data. Therefore, this discussion paper was prepared to propose some new research options and outline the required plans for supplemental data collection and analysis.

These options are not intended to achieve all of the goals and objectives specified in Battelle’s Evaluation Plan or the research activities being pursued by the University of Minnesota as part of the Mn/DOT partnership. So, a review of the evaluation priorities is needed before pursuing any of these options. These options will involve significant participation by the Mn/DOT partnership and extensive collaboration between Mn/DOT partners and Battelle. Finally, the U.S.

Department of Transportation (DOT) will need to review and approve changes in the current research plan for both Mn/DOT and Battelle before these options can be pursued.

These research options and the plans to carry out supplemental data collection and analysis form the basis of a risk mitigation plan. Since they are involved with more in-depth analysis of system performance and certain human factors responses, they also affect other areas of the Evaluation Plan.

Current Research Design

Prior to the start of the FOT season, Battelle discussed the experimental design with the Mn/DOT Office of Advanced Transportation Systems (OATS), the University of Minnesota, and FHWA. Those discussions examined specific changes to the experimental design that were necessary in order to provide the type of data that will be needed to estimate specific safety benefits. Attachment (1) is the negotiated experimental design that resulted from those discussions. Attachment (2) is a tradeoff matrix that was used to help structure those discussions and assist in making decisions about the candidate designs' features.

Battelle's safety benefits estimation methodology was a key factor considered in arriving at this design. This methodology uses various types of driving data from the Mn/DOT FOT to predict the number of crashes that might be avoided if such specialty vehicles nationwide were equipped with IVSS technologies. The types of crashes that are being considered include rear-end collisions, single vehicle roadway departures, and lane-change/merge collisions. To evaluate the benefits of vision enhancement systems for avoiding these types of crashes, driving data are used to estimate the probability of specific driving conflicts leading to crashes, as well as the probability of a crash given that a vehicle encounters such a conflict. This approach requires collecting driving data from IVSS-equipped vehicles both with and without active driver-vehicle interfaces and warning systems.

The experimental design contains provisions to deactivate the driver-vehicle interface – called the Driver Assist System (DAS) - for two of the six specialty vehicles involved in the test (specifically the McLeod County and Mn/DOT Eden Prairie snowplows) according to a planned cycle. This cycle is predicated on a period of data collection that includes at least two low-visibility events before DAS deactivation proceeds. The design recognized that if there were few snowfalls during the FOT period, DAS deactivation would be postponed or eliminated. As of the current date, there has not been a single low-visibility event.

Options to Consider

Assuming we will not have sufficient low-visibility winter weather conditions to perform the evaluation as planned, we see three primary field data collection options to consider: (1) Extend data collection to the 2002-2003 winter season, (2) Conduct controlled tests to evaluate certain performance characteristics of the system, and (3) Conduct controlled tests to evaluate drivers' ability to rely on the vision enhancement system under low-visibility conditions. These options are not mutually exclusive – except possibly from a resource perspective. Because the objective of this document is to suggest research options for further discussion, it is premature to determine the impacts on budgets.

Below we discuss how each option will affect the evaluation goals specified in Battelle's Evaluation Plan and present an outline of a proposed approach. Each option will require significant collaboration among all interested parties. For example, if Options 2 or 3 are to be pursued it will be necessary to prepare experimental designs and detailed protocols to specify the exact conditions to be tested and procedures for data collection and analysis. However, the first step is to assemble all interested parties (Mn/DOT partners, U.S. DOT, and the Battelle evaluation team) to reassess evaluation priorities and prepare detailed objectives. Once those have been agreed upon, a detailed design can be worked out that includes the types and numbers of specialty vehicles that would be involved.

Option 1: Extend Data Collection to the 2002-2003 Winter Season.

Impact on Evaluation Goals: This option preserves the current evaluation goals and relative priorities.

Evaluation Approach: This option will utilize the same evaluation approach described in Battelle's Evaluation Plan. This is the only approach that we can recommend to achieve the current goals and objectives – especially those related to estimation of safety benefits. Although additional resources will be needed to extend the FOT, the advantage of this option is that the limited data collected this year can be used to exercise the analysis models and, if necessary, make adjustments to the research design or data collection systems before the start of the 2002-2003 winter season.

Option 2: Conduct Controlled Tests to Evaluate System Performance

Impact on Evaluation Goals: This option provides for a more in-depth analysis of system performance (Battelle Evaluation Goal 3). In particular, it will provide detailed information on how the system performs under specific on-road conditions. This information is useful for estimating probabilities of various types of false positive and false negative alarms. However, data from these tests cannot be used alone to estimate safety benefits (i.e., number of crashes avoided) as specified in Battelle Evaluation Goal 1A.

Evaluation Approach: A series of on-road tests will be designed to evaluate how the system responds to various driving scenarios. All of the tests will be staged and conducted under controlled and safe conditions using current drivers of the specialty vehicles. Battelle will oversee the tests and, if necessary, accompany the drivers to assist in data collection. These are "special" tests that will be scheduled during times when both the vehicle and driver are not assigned to normal duties. They do not require adverse weather. They will be conducted while the driver has full vision of the roadway and surrounding area. All data recording and warning systems will be activated.

The following five-test series will be used to evaluate how the system will perform under various driving conditions similar to those experienced during normal operation of the specialty vehicle.

For each series of tests Battelle will prepare an experimental design after consulting with the Mn/DOT partners and DOT. Each design will specify conditions such as host and target vehicle speeds, angle of approach, on-road and off-road target type, and road geometry.

Test Series 2-1. – Off Roadway Object Detection

In this series of tests, the specialty vehicle will travel down a road at the set speed to test the forward-looking radar system's responses to various off-road objects. These tests will determine the ability of the systems to detect objects that present meaningful safety threats, and to filter out other objects. Actual roadway segments will be selected based on factors such as road geometry (straight vs. curved), number of lanes, and types of roadside or overhead objects present (e.g., guardrails, signs, bridge abutments). Although most of the roadside objects in the test corridor are mapped in the geospatial database, we will also test the system's performance when non-mapped objects are present. This might simulate the presence of temporary objects such as construction barrels or cars parked nearby but off of the roadway. The tests will be conducted with the host vehicle operating at various speeds and while simulating normal driving behaviors (e.g., changing lanes, braking, or – in the case of snowplows – plowing out of the lane to the right).

Test Series 2-2. – On Roadway Object Detection

Another function of the forward-looking radar system is to aid the driver in detection and avoidance of obstacles that are in the roadway and in the path of the vehicle. In this series of tests the specialty vehicle would travel down a roadway and encounter several different objects, such as a vehicle stopped in the road, debris, or construction barrels. A moving vehicle will be represented in a variety of different scenarios. For example, tests will be conducted with a vehicle approaching from the opposite direction (either across the median or in the same lane), the leading vehicle traveling in the same direction at a slower speed, or the leading vehicle stopped in the same or adjacent lanes. The system's response to soft tissue objects in the road such as people or animals could also be examined.

Test Series 2-3. – Side Object Detection

This series of tests will focus on the performance of the side-looking radar system. Tests will be conducted with vehicles approaching from behind in adjacent lanes on either side of the test vehicle. Tests will be conducted on straight and curved roads. Also, the relative speeds of the vehicles and separation distance between vehicles will be varied.

Tests will also be conducted at various speeds and road geometries to determine if roadside furniture (e.g. guardrails, signs, light posts) will trigger the side detection warning system.

Test Series 2-4. – Lane Keeping

Both the magnetic lateral guidance system, and the DGPS-based guidance system with lane departure warnings, will be evaluated in a series of on-road tests. In these tests the main variable of interest is the distance from the centerline (or distance to edge of roadway/adjacent vehicle).

In the case of the DGPS-based guidance, the test includes when the lane departure warning occurs (or fails to occur as planned). The experimental design will specify various speeds, road geometries, and angles of road/lane departure.

Test Series 2-5. – Rear Object Detection

Another aspect of the IVSS is the high-intensity rear-facing emergency strobe lights. The performance of this system will be evaluated in a series of tests using different types of vehicles (small car, large car, truck) at different absolute and relative speeds. We will also evaluate the sensitivity of the system for detecting vehicles approaching from behind in adjacent lanes in addition to constant bearing/decreasing range situations.

Option 3: Conduct Controlled Tests to Evaluate Drivers' Ability to Rely on the Vision Enhancement System

Impact on Evaluation Goals: This option focuses on evaluating the drivers' ability to use the vision enhancement system to accurately navigate the vehicle under low-visibility conditions. The goals of these tests include obtaining objective measures of driving performance while relying solely on the IVSS and subjective measures of the drivers' level of comfort and confidence in the system. This option provides for a more in-depth assessment of driver acceptance and human factors than was originally planned under Battelle's evaluation goal area 2.

Evaluation Approach: A series of on-road tests will be designed to evaluate how the driver performs and reacts under various driving conditions while relying solely on the heads-up display to navigate the vehicle. Tests will be conducted with blinders over the windshield in front of the driver. However, a "co-pilot" will be assigned to ensure safe operation of the vehicle during the test. Other safety precautions, such as closing the roadway to other traffic, will be needed.

Although it is not expected that drivers will intentionally operate the vehicle in this manner, these tests will demonstrate the degree to which drivers can rely on the system to navigate under sudden zero-visibility conditions such as a white-out, which may occur during snow storms, or extremely heavy fog.

All of the tests will be staged and conducted under controlled and safe conditions using current drivers of the specialty vehicles. In addition to the "co-pilot," an observer will be present to record driver reactions and interview the driver immediately after the test is completed. More in-depth interviews will be conducted following the test series. These "special" tests will be scheduled during times when both the vehicle and driver are not assigned to normal duties. All data recording and warning systems will be activated.

Two series of tests are planned, although, it may be possible to combine certain tests. One series will be used to evaluate the drivers' ability to maintain an accurate and consistent lane position, and the other on his ability to properly react to collision warnings. For each series of tests Battelle will prepare an experimental design after consulting with the Mn/DOT partners and

DOT. Each design will specify conditions such as host and target vehicle speeds, angle of approach, on-road and off-road target type, and road geometry. The designs will incorporate three operating scenarios: (1) Driver has clear view of the road with the vision enhancement system turned off, (2) Driver has clear view of the road plus an active vision enhancement system, and (3) Driver relies solely on the vision enhancement system to navigate the vehicle.

Test Series 3-1. – Lane Keeping Using IVSS Only

The driver will steer the specialty vehicle down several road segments or courses laid out on a test track. Both magnetic later guidance as well as DGPS-based guidance will be assessed. Clearly, special precautions are needed if the tests are conducted on public roads. The driver's lane position will be recorded and used to measure the accuracy and consistency of lane position, as well as the number of lane/roadway departures. Other driving parameters such as vehicle speed and brake activations will be recorded as well. The tests will be conducted with various road geometries (e.g., straight road, turns, and various curvatures).

Test Series 3-2. – Obstacle Avoidance Using IVSS Only

The driver will operate the specialty vehicle on a road segment or test track with various moving and stationary objects being introduced in the path of the vehicle, in an adjacent lane, or off-road ahead of the vehicle. The purpose of these tests is to record the driver's reaction (deceleration, braking, steering) to the various warnings provided. Tests will be conducted at various speeds of the test and target vehicles and road geometries. The tests will only be conducted with objects that the system will recognize as determined in Test Series 2-1 to 2-3.

Special precautions are needed in conducting the tests specified under Option 3. However, these tests are critical to understanding the degree to which drivers can rely on the IVSS to operate the vehicles under low-visibility conditions. We need to understand how the drivers' react when using the system under unpredictable conditions and their level of comfort and confidence in using the system.

Attachment (1)

Revised Experimental Design Strategy for the Mn/DOT Specialty Vehicle FOT

During a conference call on September 19, 2001 involving Mn/DOT, the University of Minnesota IVL, and Battelle, the group discussed the experimental design for the Mn/DOT specialty vehicle FOT evaluation. Prior to the call, Battelle proposed a design in which the four snowplows and the patrol car would operate for periods of time with the DAS driver interfaces turned off on the test road (Trunk Highway 7). We proposed that design to meet data needs for analyzing single vehicle roadway departure crashes. The two major concerns with this plan were reducing the amount of data collected with the driver interfaces on and the potential impact on the drivers of turning the systems on and off too frequently. During the conference call on September 21, 2001 involving Mn/DOT, the University of Minnesota IVL and HFRL, Battelle, and the U.S. DOT, a revised plan was discussed that alleviates most of these concerns.

This plan calls for all vehicles' driver interfaces to be turned on at the start of the FOT. This will allow all last-minute bugs to be worked out of the system. These data will be transferred to Battelle within a week of being collected. Battelle will store and use these data to start identifying driving conflicts and exercising our analysis models. After all issues with the collection and transfer of the data to Battelle have been resolved – and after Battelle has had time to start analyzing the data – we will arrange some driver interface off time. Driver interfaces will not be turned off until at least two severe snow events have occurred. The definition of severe snow event is necessarily vague and includes a requirement for low-visibility conditions. Battelle suggests that we use John Scharffbillig's opinion to make this determination here and in other areas of the design strategy where needed. At this point, the Eden Prairie and McLeod County snowplows' driver interfaces will be turned off. The driver interfaces will remain off until at least one, but preferably, two severe snow events occur. We will then turn the interfaces on again.

Battelle will analyze the data collected up to this point and make an assessment of how our methodology is working, and then we will recommend how the design should proceed. If the methodology shows promise, we will recommend that we have the same two snowplows (Eden Prairie and McLeod County) follow a schedule of driver interface on and off time. The schedule would be to switch the driver interface status every three weeks. If the drivers were using the system only in very severe conditions, then we would revise the driver interface status to be dependent on weather events as well. We will maintain three weeks on and three weeks off unless there are no severe weather events during a three-week period. In this case, the system would retain its current status until a severe weather event is observed. Again, we recommend that John Scharffbillig make this determination. If, on the other hand, the drivers find the system helpful and use the system in less severe conditions, we will maintain the three-week schedule. If Battelle determines that we cannot successfully apply our methodology to these data, then the driver interfaces will remain active for the remainder of the winter.

Attachment (2) Mn/DOT IVI FOT Experimental Design Considerations

	Approach A	Approach B
Concept	Map centerline of selected segments of snowplow routes outside of test corridor	Make DAS inputs inactive while within corridor by turning down intensities of HUD and audible alarms (switch off?)
	Operate all 6 vehicles' DAS in test corridor continuously during adverse weather ops	Operate all 6 vehicles with active and inactive DAS while on test corridor, according to a predetermined schedule
	Compare performance with inactive DAS while on roads that are "comparable" to the test corridor	Compare performance with active & inactive DAS while on the same roads
	Similarity of weather outweighs dissimilarity of road	Similarity of road outweighs dissimilarity of weather
Pro	Maximizes overall data collection rate - particularly important if minimal adverse weather conditions	Maximizes comparison of driving performance with and without DAS while controlling variables to greatest degree
	Snowplows only on test corridor during part of shifts anyway – comparable roads concept expands data	Only way to make comparisons of driving performance with identical roadway geometry & roadside furniture
Con	Cannot compare drivers' performance with & without DAS on specific road segments. Differences in traffic patterns may also skew comparisons	Ideally requires 50% DAS off-time during adverse weather operations
	If roadside furniture and other features are not mapped, driving performance on that road cannot have as valid a comparison as performance on test corridor with DAS on & off, except in terms of average lanekeeping ability	Less anecdotal data on ambulance emergency response times
		Low snowfall could reduce already limited data beyond point of significance