2004-09

Final Report

System Performance and Human Factors Evaluation of the Driver Assistive System (DAS)

Intelligent Vehicle Initiative
Specialty Vehicle Field Operational Test

Research

Technical Report Documentation Page

1. Report No. MN-RC 2004-09	2.	3. Recipients Accession No.
4. Title and Subtitle System Performance and Human Factors Evaluation of the Driver Assistive System (DAS)		5. Report Date December 2003
		6.
7. Author(s) Mick Rakauskas, Nic Ward, Craig Shankwitz, Max Donath		8. Performing Organization Report No.
9. Performing Organization Name and Address HumanFIRST Program 1100 Mechanical Engineering 111 Church Street S.E. Minneapolis, MN 55455		10. Project/Task/Work Unit No.
		11. Contract (C) or Grant (G) No. (c) 74708 (wo)160
12. Sponsoring Organization Name and Address Minnesota Department of Transportation 395 John Ireland Boulevard Mail Stop 330 St. Paul, Minnesota 55155		13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code
15. Supplementary Notes http://www.lrrb.gen.mn.us/PDF/200409.pdf Part of the: Intelligent Vehicle Initiative Specialty Vehicle Field Operational Test		

16. Abstract (Limit: 200 words)

This study aimed to determine the usefulness of the Driver Assistive System (DAS) in the context of plowing roads during low-visibility conditions. Driving performance, driver workload, and system performance were to be compared in a field operational test (FOT). Geographical location of the driver's route proved to play a large part in the desirability and perceived reliability of the system, as rural drivers preferred the system due to the lack of lighting and visual guidance while driving in low-visibility conditions. Most drivers did not have problems remembering how to use the DAS, and that the system made them feel safer and more in control while driving. The haptic seat was praised for giving warnings while letting them keep their eyes on the road or performing other in-cab tasks and their ideal configuration would be to use the haptic seat and/or the HUD. Due to an uncharacteristically mild winter weather conditions, it was decided that the FOT would not provide enough experience using the DAS during low-visibility conditions to make reasonable conclusions on driving performance. Therefore, it was necessary to use an additional experimental design with a track test, which is discussed in a supplemental document (Rakauskas et al., 2003).

17. Document Analysis/Descriptors Driver Assistive System Snowplow Field Operational Test	Intelligent Vehicle Initiative DGPS	18. Availability Statement No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 124	22. Price

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Specialty Vehicle Field Operational Test

FINAL REPORT

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December 2003

Published by
Minnesota Department of Transportation
Research Services Section
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St. Paul, Minnesota 55155-1899

ACKNOWLEDGEMENTS

The researchers would like to thank Mn/DOT for their help and support throughout the project. We would like to specifically thank John Scharffbillig for all his hard work in traveling, scheduling, and late nights during the FOT and track test. In addition, thanks are also due to our ten drivers who participated in both parts of the study; their outright honesty was greatly appreciated.

Finally, thanks also to Dan McGehee from the University of Iowa for his advice and commentary during the Quality Assurance stages of this project report.

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EXECUTIVE SUMMARY

This project is a study to determine the usefulness of the Driver Assistive System (DAS) in the context of plowing roads during low-visibility conditions. A quasi-experimental design in the context of a field operational test (FOT) was originally used to compare driving performance, driver workload, and system performance in a naturalistic setting.

During the drivers' regular routes, the DAS was enabled while traveling one direction (either East or West, alternating days) and disabled while traveling in the opposite direction. The DAS' vehicle data acquisition system (vehDAQ) always collected driving performance and subjective data whether the DAS was enabled to the driver or not.

Driving performance, critical incident, and safety measures were collected continuously throughout the drivers' routes. Mental workload and usability were prompted from the driver at set points along the route through the touch screen interface. Drivers' subjective opinions were collected through monthly interviews and surveys completed at the end of the season.

Overall, it was found that geographical location of the driver's route played a large part in the desirability of the system. Drivers in more rural areas preferred the system due to the lack of lighting and visual guidance while driving in low-visibility conditions.

Based on the framework for our research questions, general results from the subjective comments and interview sessions with snowplow operators during the FOT were as follows:

- Operability
    - Most drivers did not have any major problems remembering how to use the DAS.
    - It was difficult for some drivers to remember or understand what it meant when HUD objects changed color.
- Safety
    - Drivers thought the system made them feel safer and more in control while driving.
    - Drivers in rural areas felt safer using the system than metro drivers.
    - The haptic seat was praised for giving warnings while letting them keep their eyes on the road or performing other in-cab tasks.
- Acceptance
    - Drivers' ideal configuration of the DAS would be to use only the haptic seat, the HUD, or a combination of both the haptic seat and HUD. Drivers did not include audio warnings in their ideal configuration.
    - Drivers felt that the HUD combiner screen could be improved to make it more stable and easier to adjust.
    - Geographic location of a driver's route, which impacted the types of visibility conditions experienced, played a large role in a driver's willingness to use the system.

- Reliability
    - Experience with the DAS increased drivers' trust that it would function as they expected.
    - Drivers in rural areas felt the DAS was more reliable than near-rural and metro drivers.
    - Rural and near-rural drivers trusted the system more than metro area drivers to provide them with accurate and reliable information.

In early February, the lack of snow and low-visibility conditions was noted as a result of uncharacteristically mild winter weather conditions. Discussions between the researchers and Mn/DOT were held and it was decided that the FOT would not provide enough experience using the DAS during low-visibility conditions to make reasonable conclusions. Therefore, it was necessary to use an additional experimental design with a track test to compare driving performance, driver workload, and system performance under artificial low-visibility conditions. The objective and subjective data from this track test are discussed in a supplemental document (Rakauskas et al., 2003).

For our track testing, eight plow operators who participated in the FOT drove a DAS-equipped plow on the Minnesota Road Research Project's Low Volume Roadway (Mn/ROAD) during a nighttime experimental session. Drivers experienced four driving conditions: clear visibility (C), low visibility consisting of headlight blinders and window tinting (LV), the LV condition with DAS assistance (DAS), and the LV condition with DAS assistance that occasionally transitioned to a 3M magnetic tape lane assistance interface (TRAN).

The TRAN condition was included to examine how drivers performed under conditions of unstable GPS signal fix as well as to test our implementation of the magnetic tape system interface. It should be noted that the 3M display used in this project is not the same in terms of location or content as the original design. Our design used this technology to display an active view of where drivers are in their lane at that moment on the HUD. The original design called for it to be used as a lateral warning using methods such as peripheral warning lights, audio, or haptic seat warnings.

While driving, operators also had to continuously complete a loading task presented on the DAS interface touch panel. They also were to detect and avoid an obstacle placed in their path once per experimental circuit. After driving each condition, operators completed mental workload and trust questionnaires and answered questions asked in an interview format. After testing was completed, a final interview was conducted and they completed a survey on their entire experience with the DAS.

Unlike the FOT, it was only possible to focus on Safety and Acceptance objectives during the track testing. The drivers' objective performance on the test track primarily focused on the Safety objective and was quantified by using four measures of driving performance. The general results from these objective measures were as follows:

- Lane Position / Lane Departures
    - The DAS enabled drivers to maintain consistent lane position as well as while driving the low-visibility (LV) condition. It also allowed drivers to drive as well as, and sometimes better than, they could during the clear-visibility (C) condition.
    - Drivers seemed to be focused most on maintaining their lane position. In doing so they compensated by performing more frequent steering corrections and experiencing more mental workload. This effect became more prevalent as the conditions became more demanding, especially in the DAS assisted (DAS) and DAS transitioning to the 3M system (TRAN) conditions.
    - Drivers did not often depart from the lane, but when they did it seemed that DAS assistance (both DAS and TRAN conditions) allowed them to react more quickly to the departure.
- Steering
    - Drivers made fewer steering corrections while assisted by the DAS (DAS and TRAN conditions) than while driving unassisted in low-visibility.
    - There were few differences in steering variability between using the DAS and driving unassisted in low-visibility. However, trends suggest that more variability was present during the DAS assisted conditions (DAS and TRAN), indicating that drivers may have been utilizing the additional lane position information.
- Speed
    - Driving while using the DAS during low-visibility conditions did not change speed performance and aided the driver by providing additional information about the environment.
    - The average speeds during all of the low-visibility conditions were similar, whether assisted by the DAS or not. These speeds were slower than when driving under clear conditions, indicating that drivers thought that the low-visibility conditions were more mentally demanding.
    - Speed variability while using the DAS was also comparable to that of normal low-visibility conditions. However drivers were more variable when transitioning between the DAS and 3M system (TRAN). This suggests that the DAS preview of the road ahead may better allow drivers to maintain stable speeds and to predict changes in the driving environment than our implementation of the 3M system did.
- Hazard Avoidance
    - Drivers' time to contact the hazard while assisted by the DAS (DAS and TRAN) was similar to that when unassisted in low-visibility conditions (LV).

The drivers' subjective results from the test track primarily focused on the Acceptance objective and were quantified through questionnaires and interview sessions. The general results from these subjective measures were as follows:

- Mental Workload
  - More mental effort was reported while assisted by the DAS both under normal conditions (DAS) and while transitioning to the 3M system (TRAN) than while driving unassisted in the low-visibility condition. This was expected since drivers were presented with and were expected to mentally process more information while assisted in the DAS assisted conditions (DAS and TRAN).
  - Drivers felt that the frequent loss of GPS signal while transitioning between the DAS and 3M system (TRAN) took a similar amount of effort as driving with the DAS under a constant GPS fix (DAS).
  - Drivers seemed to compensate for the additional workload while assisted by the DAS (DAS and TRAN) by lowering their speed and focusing on maintaining consistent lane position.
- Usability
  - Drivers found both the DAS (DAS) and transition to the 3M system (TRAN) conditions to be quite useful during low-visibility conditions.
  - Drivers did not feel that the system was completely satisfying. They felt the system provided useful information but that they might like this information in a different format/implementation.
  - Drivers felt that the ideal configuration would be to use the haptic seat lateral warnings, the HUD, or a combination of the seat and HUD. Most drivers did not care for the audio lateral warnings.
- Trust
  - For the most part, drivers trusted the DAS whether they were experiencing transitions to the 3M system (TRAN) or not (DAS).
- Interviews
  - Overall, drivers liked the DAS and felt there were benefits to using it when the situation warranted.
  - Drivers liked being able to customize which components were on, depending on the situation and their preferences.
  - Some drivers felt that using all of the components together was overwhelming at times.
  - Drivers would like a less bulky system that provides them with a more stable view of the road. This includes not only increasing the stability and consistency of GPS signals but also the stability of the HUD combiner.
  - Drivers were supportive of seeing future iterations of the DAS.

Many of the trends found were consistent with our previous thoughts on how the DAS would perform. However, due to the small number of drivers tested in the FOT and track testing studies there was low power for our statistical analyses. Though this resulted in a reduction in significant findings, the trends have been presented as tentative effects of the system. We encourage further research with the DAS on larger numbers of drivers or in a more powerful study design.

It seems that if the DAS is to be released on a broader scale, some changes need to be made not only in how the system functions but also in how it is implemented. Some of the more critical issues to be dealt with are as follows:

- Warn and assist drivers when the system is about to lose it's essential GPS signal.
- Make the HUD combiner more stable.
- Make essential functions of the DAS more accessible on the interface.
- Make basic system functions on the interface more understandable for plow drivers. This includes limiting the amount and format (modality/coding) of the information presented.
- Re-evaluate the necessity of DAS components, such as the audio lateral warnings.

Some changes have been made to the DAS since the time of this testing. The HUD combiners have been redesigned and a smaller interface the size of a PDA has replaced the full touch screen panel. These improvements along with other advancements are now being tested in several plow field operational tests.

1 INTRODUCTION

DRIVING ASSISTIVE SYSTEM

The Driving Assistive System (DAS) is comprised of a Differential Global Positioning System (DGPS), on-board high accuracy geospatial database, on-board computers, forward looking radar (Figure 1.1), and a driver interface system which provides lane position information and warnings utilizing a Head Up Display (HUD), a haptic seat, audio feedback and a driver control panel display.

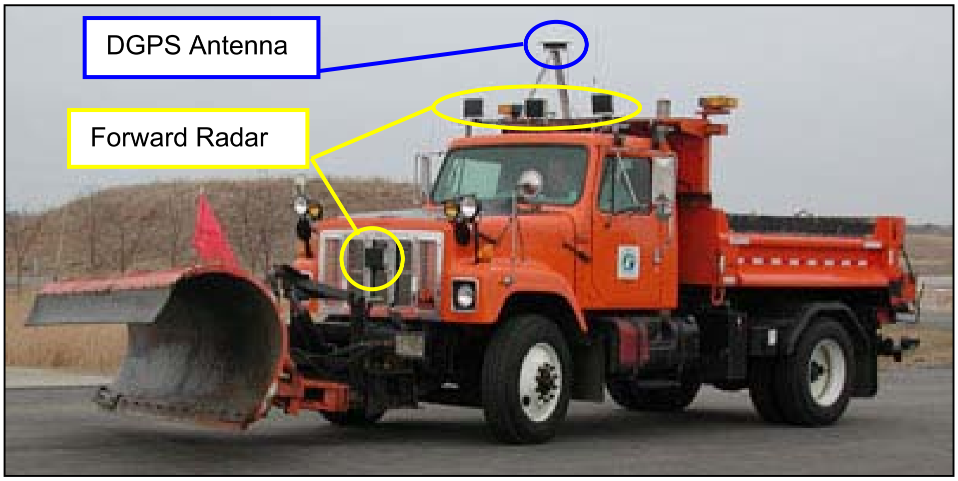


Figure 1.1. View of the radar and DGPS units on a plow equipped with the DAS.

The purpose of the HUD was to assist the driver in consistently seeing the lane boundaries. The lane boundaries are continuously projected in the HUD to infinity (Figure 1.2).

a. 

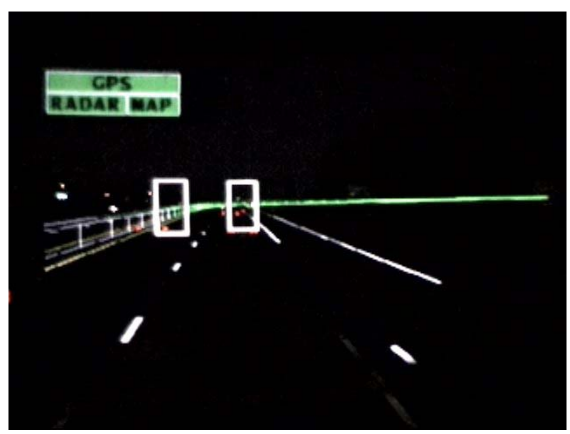
b. 

Figure 1.2. Views through the HUD: a) First person view of road lines as seen during a curve in the road, and b) HUD image of two radar targets that are more than 50 feet away or 3 seconds to contact.

Lateral warnings were provided by haptic, audio, and visual lane "warnings" when the truck was determined to be departing the lane/shoulder. On the HUD, the lane boundary about to be crossed would change color from white to red. The haptic warning was a directional vibration of the driver's seat to indicate departures to the left or right of the lane. The audio warning was a constant rumble strip sound that also presents a warning on the left or right spatially, relative to the lane departure.

In addition to lateral alerts, a radar system alerts the driver when an object not located in the geospatial database is detected within 350 feet of the front of the truck. The driver is alerted by having a square indicator appear on the HUD in the location of the object (Figure 1.2b.). The size and color of this indicator are relative to the distance of the object from the truck; for example, obstacles within 50 feet or three seconds of being hit were larger and red, while obstacles further away were white and smaller (depending on distance from the truck).

The system also included the 3M magnetic tape lane detection system, which consists of magnetic tape applied to the road and a sensor attached to each side of the front bumper. This system was included as a backup for when the DGPS signal is lost, giving the driver a secondary interface for maintaining lane position. The 3M system presents a metered line with a moving indicator on the HUD. When the truck is in the center of the lane, the indicator is located on the center "0" point of the line. When elsewhere in the lane, the indicator points to the distance (in feet) that the truck is off center.

PROJECT BACKGROUND

For an in-depth project overview and review of previous related work completed by researchers outside of the University of Minnesota, see University of Minnesota's Intelligent Vehicle Initiative Specialty Vehicle Field Operational Test (2002). This document has also been a key source for the following review of previous project results from human factors work completed at the University of Minnesota.

Human factors work undertaken by the University of Minnesota during this contract consisted of four components. The first component was a simulator study to determine both the effectiveness of lane departure and collision avoidance warnings to drivers, and whether a particular combination of warning modality (haptic, visual, or auditory) was more effective than other combinations. The two simulator studies are described in Harder, Bloomfield, and Chihak (in press).

The second experiment was a field study primarily to determine whether drivers with no previous exposure to this DAS could effectively use it under conditions of zero visibility. The field test was conducted on a closed track at the University of Minnesota Rosemount Research Station in Rosemount, Minnesota. For this field test, the objectives were to determine whether experienced snowplow operators were comfortable and could drive on real roads in conditions of zero visibility, using the integrated system tested in simulator experiments.

This field test demonstrated that it was possible to drive a snowplow around a 4.2-mile track with several sharp turns when the visibility was zero using only the DAS (the forward view was completely occluded with curtains mounted inside the cab). Even though they could not see the actual road surface, the snowplow operators drove at speeds that were reasonable for the environment. It was thought that they "felt" the road surface as they drove it through the proprioceptive information that they were accustomed to receiving while driving on snow covered roads. The Rosemount Field Test is described in full by Bloomfield and Harder (in press). An earlier account of both the simulator studies and the Rosemount Field Test appears in the Detailed Design Report delivered to the Minnesota Department of Transportation (University of Minnesota, 2001).

The third component was an experiment involving ambulance drivers and state patrol officers, who normally drive at higher speeds than snowplow operators. This test was motivated by the results of a pilot simulator study in which test subjects showed a propensity to "overdrive" their vehicle when provided with the DAS. Based on this finding, it was hypothesized that adding motion cues to the head up display (HUD) would provide a driver feedback indicative of their present speed, and would reduce the tendency of a driver to "overdrive."

To test this hypothesis, Brainerd International Speedway in Brainerd, Minnesota was leased for a five-day period. The track was mapped, and both ambulance and state patrol drivers followed a specific protocol aimed at determining whether the presence of motion cues in the HUD had a positive effect on speed regulation. Results from this study indicated that the motion cues did result in lower vehicle speeds, and as a result motion cues were designed into the HUD that was released for the FOT. The results of the Brainerd study are documented as an appendix to the Detailed Design Report submitted to the FHWA (Ward 2001).

The fourth and current component has been to determine if using the DAS enhances the performance of specialty vehicle operators in conditions of limited visibility. This was attempted during the winter of 2001-2002, in the context of an FOT. However, a lack of low-visibility conditions has caused the researchers to suggest the continuation of the FOT for another season.

2 RESEARCH OBJECTIVES FOR HWY7 PHASE II

FRAMEWORK FOR RESEARCH QUESTIONS

To answer the question about 'what' data is needed for a system evaluation, it is useful to adopt a framework that encompasses the main system objectives as illustrated in Figure 2.1:

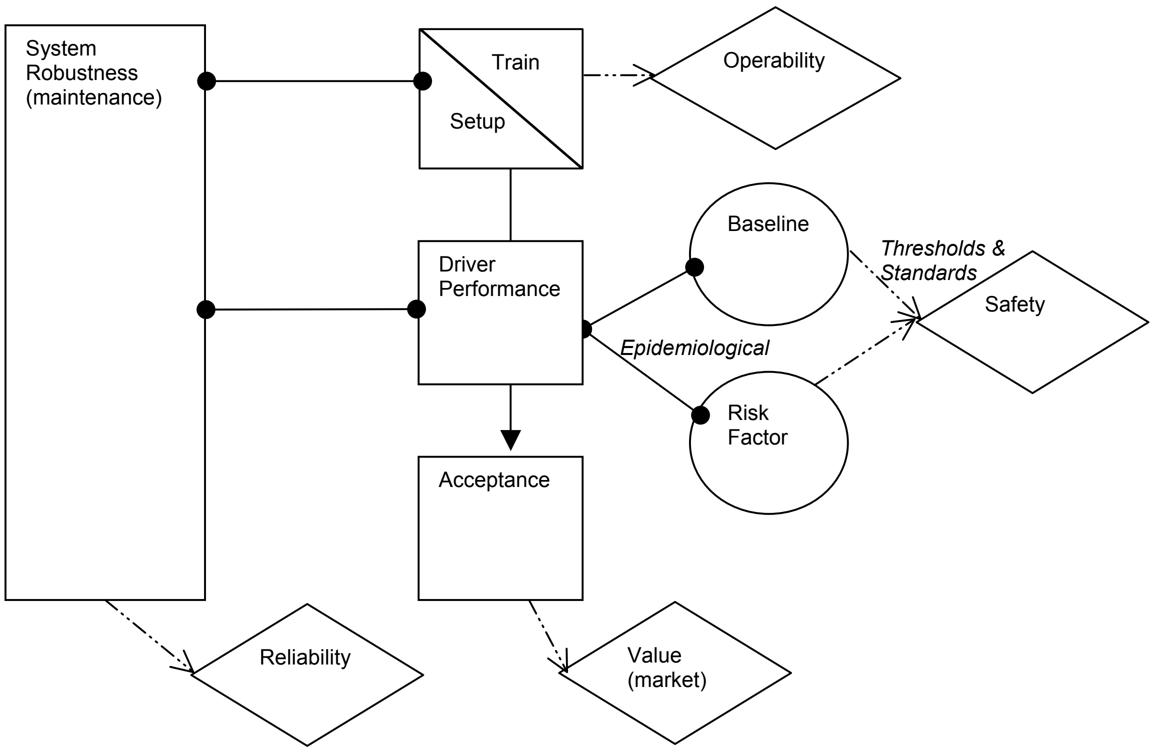


Figure 2.1. Framework of evaluation objectives (Note: diamonds = evaluation goals; squares = data collection; circles = methodology).

- **Operability** – The operation of a system should be easily learned and this knowledge should be memorable. Intensive training for operating instruction that is quickly forgotten if the system is not used for some time is not acceptable. Similarly, the setup of the system for operating conditions and operator preferences should be simple and restorable. Complex procedures for setting up the system and the need to repeat the procedure on each occasion are also not acceptable. For these reasons, data should be collected during the training and setup stages of the evaluation. This may include observational data about time required to learn the system or to set up the system configuration, errors in system operation or incorrect setup, and questionnaires directed to operators about their experience with the training and setup activities.

- **Safety** – A system should improve safety by supporting performance that reduces crash risk. In the absence of actual crash data, safety can be indirectly evaluated in terms of proxy measures that have a theoretical link to crash risk. Such measures may be based on performance variability such as variation in lane position, headway, speed, or entropy of steering control. These measures are based on the premise that the greater the variability in a control system, the more probably a system failure (crash). Measures may also be based on the notion of 'safety margin' relating to the distance between the vehicle and a safety hazard. Such measures may be defined in terms of physical distance (headway distance, position from lane boundary) or temporal distance (e.g., time-to-line crossing, time-to-contact).

An evaluation supposes a comparison of the target system to a valid baseline condition. In this sense, the determination of a safety effect should be relative to an alternative system. The baseline condition(s) should be typical of existing systems and differ from the target system only in terms of the specific features that define the new functionality. This ensures that the evaluation is valid and specific to the system features.

Often, systems may be designed with a goal to improve safety by reducing a specific type of crash that has an associated risk factor. For example, epidemiological evidence has related certain crashes to particular human factors such as fatigue or distraction. In this case, the system should be evaluated in the context of these risk factors. This improves the validity of the evaluation and provides a relevant context in which to infer the intended safety benefit (in relation to the specified crash type). In general, the principle for the evaluation is to demonstrate that the system protects the impairment effect of the identified risk factor as illustrated in Figure 2.2.

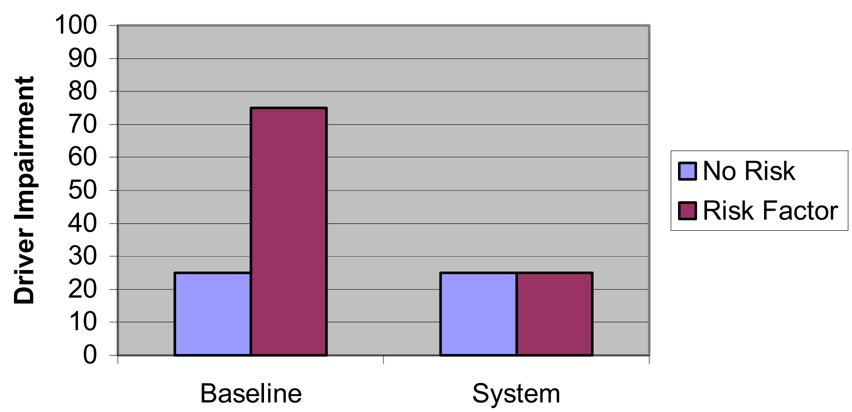


Figure 2.2. Illustration of system benefit in the context of risk factor.

The quantification of a safety effect is tenuous for two reasons. First, as already discussed, the measures of driver performance are often indirect measures of safety. Second, there is no universal threshold to define a practical change in safety. That is, whereas it is possible to demonstrate a statistically significant difference in operator performance between target and baseline systems, there is no consensus about general criteria to justify a level of performance as 'safe', nor are there performance standards applicable to particular systems to define safety. Therefore, the practical significance of a statistical difference obtained in an evaluation study is often a matter of interpretation for the funding agency and those considering deployment policy.

- **Acceptance** – The value of the system should be apparent to the operators. In spite of the system goals, it will not be utilized if the operators do not appreciate the utility of the system and find its operation satisfying. For these reasons, data should be collected after operators have had considerable exposure to the system. This may include observational data about the frequency and duration of system use, and questionnaires directed to operators about their perceptions (e.g., understanding of system operability), attitudes (e.g., judgments about value of system), and recommendations regarding the system (e.g., identified problems and suggested changes).

- **Reliability** – The operation of a system should robust and maintainable. A system that operates unreliably will destroy system credibility for the operator. An unreliable system that requires intensive and expensive maintenance will also not be economically viable. For these reasons, data about failure rates should be collected during the evaluation period for all system components (i.e., hardware, software, infrastructure) as well as documentation of all maintenance efforts to operate the system.

METHODOLOGIES

There are three generic options that were proposed for the evaluation methodology:

- Test Track – Controlled experimentation on test track
- Field Study – Partially controlled experimentation on roads
- Operational Test – Observation of system in operational context

The selection of methodology depends on the evaluation objectives (see Figure 2.1). On the one hand, test track studies are most conducive to safety evaluations because of the practicality of inducing high-risk conditions in a controlled environment. On the other hand, valid conclusions about operability, sustainability, and acceptance are better considered in the actual operating environment due to the test track's low external validity.

Ultimately, it was initially decided to conduct another Field Study, while also agreeing that if there were not enough low-visibility weather conditions or many low-visibility instances did not seem likely to occur during the season, terms for a Test Track study would be explored.

In addition to the evaluation objective, the choice of methodology must also take into account those issues that can limit the conclusions of an evaluation. Several factors can be identified that may have limited the application of results from the Phase I evaluation:

1. Hardening – The system and its inherent technology may not have been robust enough, such that system weaknesses may have resulted in negative perceptions by operators.
2. Snow – This is a system primarily intended for snow operations, but there were insufficient snow conditions to evaluate the system.
3. Control – Operational tests typically cannot control the incidence of other factors that may influence operator performance and perceptions such that the effect of the system may be lost in the naturally occurring variation of operating conditions. These factors

can relate to the individual demographics (age, experience), individual state (fatigue, stress), or environment (weather, route, time, traffic).

4. Comparison – The operational test may not have included sufficient valid baselines against which to compare the system for a fair and meaningful evaluation.
5. Reliability – By virtue of the inherent inability to control snow conditions, there were too few relevant data points to support reliable conclusions.
6. Rationale – In the absence of a comprehensive and rational framework for identifying research objectives, it is possible that the methodology did not provide the type of results that can support policy about future research needs and eventual system deployment.
7. Use – Operators may use a system in a manner contrary to the system design such that their perceptions and attitudes about the system may be inappropriate.

As shown in Table 2.1, the issues that may limit an evaluation are not avoided by all methodologies.

	Test Track	Field Study	Operational Test
Hardening	✓	✓	✓
Snow	?	×	×
Control	✓	✓	?
Comparison	✓	✓	?
Reliability	✓	×	×
Rationale	✓	✓	✓
Use	✓	✓	?

Note: ✓ (issue resolved), × (issue not resolved), ? (possible resolution of issue)

Table 2.1. Evaluation Issues in Relation to Methodology

However, as shown in Table 2.2, some methods can be proposed as possible solutions to overcome these methodological issues. Admittedly, these are only tentative proposals given the necessity to consider practical constraints. As such, these are only tentative concepts for methods that may be applied to the evaluation of the system. However, it is more advantageous to consider an ideal methodological design and then modify it to practical constraints than it is to limit the imagination of the design at the outset.

	Test Track	Field Study	Operational Test
Hardening	Prolonged systematic testing for component failures.	Prolonged systematic testing for component failures.	Prolonged systematic testing for component failures.
Snow	Install snow machines on track (or vehicle) to cover section of track surface (or vehicle windscreen); fix barrier to windscreen filled with amounts of Styrofoam beads with blower to simulate snow particles; introduce road hazards (vehicle mock-up).	×	×
Control	Create identical environment conditions and driving context; choose single age and experience cohort or compare drivers to themselves in all conditions.	Paired drivers – one with system and one without (identical trucks); assigned to test route on snow occasions; plow opposite directions at same time (controlling all environment factors except direction route); alternate between vehicle and direction on successive occasions so the effect of these other factors are 'balanced'.	Some practical variation on Field Study.
Comparison	Provide 'golden standard' by driving in optimal day conditions along test track; several laps produce 'mean path' that can be used to normalize performance in other conditions; comparison conditions without system and with system.	Provide 'golden standard' by driving in optimal day conditions along test route; several passes produce 'mean path' that can be used to normalize performance in other conditions; comparison conditions without system and with system.	Provide 'golden standard' by driving in optimal day conditions along test route; several passes produce 'mean path' that can be used to normalize performance in other conditions; comparison conditions without system and with system.
Reliability	Snow assured (or simulated); repeat trials for multiple data points	× (repeat trials for multiple data points)	×
Rationale	Use framework; induce safety critical events (e.g., obstacle in lane)	Use framework	Use framework
Use	Experimenter set use of system	Experimenter set use of system; Lockout system use by linking to roadside visibility measurement stations	Lockout system use by linking to roadside visibility measurement stations

Table 2.2. Proposed Methods for Limitations

PROPOSED WORK PLAN

Initially, Mn/DOT did not envisage this work completed on a test track on a controlled experiment. Instead, Mn/DOT wished to pursue the evaluation objectives in the context of an operational test while acknowledging the methodological limitations of this approach (**Error! Reference source not found.**). However, to ensure sufficient data to support valid conclusions about the effect of the evaluated system (Table 2.2), it was necessary to have certain control over the operational setting. For safety reasons, no stress was introduced onto the driver to measure the effect of the system. Indeed, the probe questions from the display in the vehicle were not intended to increase operator workload.

Also, baseline driving is needed from each driver on the routes they operate. This can be obtained by averaging several trips along the route during optimal conditions. This provides a 'golden standard' against which to compare the performance impairment of inclement weather and the effect of the system.

Fourth, the plow should only be able to use the system while driving in one cardinal direction, switching directions of availability on a daily basis. This allows for a comparison of the system that does not confound weather conditions or time of day as illustrated in Table 2.3.

	System Truck	**Paired Truck**	**Paired & alternate route**	**Paired & alternate route, drivers**
Factors Present:	System			
	Weather	Weather	Weather	Weather
	Road Surface	Road Surface	Road Surface	Road Surface
	Road Geometry		Road Geometry	Road Geometry
	Driver			Driver
	Time	Time	Time	Time
	Truck			
Confounding Factors:	Comparing the system truck to the paired truck confounds the effect of the system with the following factors that also distinguish between the system truck and paired truck: • road geometry, • driver, • truck* That is, it is not possible to conclude that the system produced the observed differences in performance, or if these other factors did instead.		• Driver • Truck	• Truck

Table 2.3. System Comparison and Confounding Variables.

* The only way to avoid the confounding effect of the truck is to alternate the system between the paired trucks. However, this is impractical such that it is sufficient to use trucks that are similar in operating characteristics.

OBJECTIVES

The aim of the field operational test and the track testing was to provide information on the operability, safety, and acceptance of the DAS that was not gleaned during phase I. Focus for this phase is on the DAS in snowplows. Though a patrol car will also be using the system, only subjective survey data will be collected from this vehicle's driver. The amended track testing provided information that was not gleaned during Phase I or II during field operation testing due to unfavorable weather conditions (see Rakauskas et al., 2003).

The objectives of both portions of the study are to provide data with respect to the following questions:

1. Does the system support driver performance in a manner consistent with reduced crash risk?
2. Does the system support driver performance in a manner consistent with improved productivity?
3. Is the value of the system apparent to operators?

3 METHODOLOGY: FIELD OPERATIONAL TESTING

The study used an experimental method with snowplow drivers in a Field Operational Test (FOT) while plowing their assigned routes of Minnesota State Highway 7 (MN TH7).

PARTICIPANTS

The experimental sample was comprised of 10 Minnesota Department of Transportation (Mn/DOT) snowplow operators assigned to routes on the MN TH7 corridor. The average age of the drivers studied was 38 years (minimum 26, maximum 60 years). On average, these drivers have been working for Mn/DOT or McLeod County for seven years (minimum one, maximum 38 years) and have eight years of plowing experience (minimum one, maximum 36). Five of these drivers participated in the field operation testing during the previous season, and one driver reported having experience with similar systems (using GPS guidance and HUDs) while serving in the armed forces. One of the drivers was female.

EXPERIMENTAL DESIGN

This portion of the study used a "within subjects" design, where drivers were measured with the DAS both activated and deactivated on different sections of the assigned route during the same plowing session. More specifically, on odd-numbered days, the system was enabled while plowing eastward and disabled when plowing westward (note: that way, on the first day of the month, the system was **E**nabled going **E**astward…), and vice versa for even-numbered days (see Table 3.1).

Direction	Day	
	Odd	Even
East	Enabled	Disabled
West	Disabled	Enabled

Table 3.1. Depiction of when DAS was enabled and disabled on Highway 7 depending upon which direction the plow was traveling.

This implies that the system status can be compared for the same driver, truck, route, and weather conditions (assuming that the weather was consistent and broad enough to cover the entire route). In this design, only direction of travel was not controlled in the experiment. However, the order of system activation along the sections of the route was counterbalanced to limit any confounding effects.

Equipment

Vehicles

The vehicles were single-axle trucks owned, operated, and maintained by the Minnesota Department of Transportation (Mn/DOT) and McLeod County at these stations:

- Eden Prairie
- Shakopee
- Hutchinson, at Hutchinson Area Transportation Station (HATS)
- McLeod County, at HATS

The trucks were outfitted with the same Driving Assistive System used in Phase I of this project, as explained above. Minor *technological* updates were made since Phase I testing, but no system functionality was added or removed aside from material added by the Human Factors researchers.

Training Materials

During the instructional session at the beginning of the season, each driver received a handbook containing material relating to the system and the study. The handbook was a one-half inch binder that contained the following sections of material, which can be found in Appendix B:

- Contact Information – The cover of the binder contained contact information and reasons to contact researchers. It also listed the Research Subjects' Advocate Line of the University of Minnesota, for the participants who may have had concerns they did not wish to talk to the researchers about.
- Introduction Letter – Welcome and brief explanation of what handbook contents.
- Consent Form – Copy of the consent form signed by drivers.
- Overview and Instructions – Description of the study, note on privacy, things that should be measured, and an image of video that would be recorded.
- Your Opinions and Suggestions – Description of the methods used to collect their opinions while driving, during interviews, and in an end-of-season survey.
- Driver Initiated Data – Quick description of the system and how, when, and why they should signal comments and events ("critical incidents").
- System Initiated Data – Description of questions asked of the drivers at the mid-point of each route and how to answer them.
- End-of-Route Procedures – Description of what drivers should do when they return to the station and how to answer on-screen questions before shutting down the truck.
- Settings Panel – Description of how to use the settings panel to turn on/off or adjust settings of system components.
- Interview Questions – Copy of the questions that were asked during interview sessions.
- End of Season Survey – Copy of the questions that were given to drivers to answer at the end of the season.

A set of laminated quick reference cards were also attached to the DAS inside each plow (Appendix C). These cards were meant to supplement in-vehicle training and the handbook. They contained information relating to the following four topics:

- Main Panel: Sensor Status – Information about the DAS system status that appears on the touch screen Main Panel display.
- Brightness Adjustment & Settings Panel – Description of how to adjust the projector brightness and how to adjust components of the DAS.
- Comment and Event Buttons – Description of what the Event and Comment buttons do and when to use them, and how to answer the questions that come up after indicating a Comment.
- How to Answer Panel Questions – Descriptions of when questions will appear and instructions on answering them.

Route

The FOT took place primarily on Minnesota State Highway 7 (MN TH7) between Hutchinson, MN to the west and I-494 in Minnetonka, MN to the east. Because of the involvement of McLeod County in the FOT with their drivers and snowplow, a section of County Road 7 (CR 7) near MN TH7 was also included in the FOT. Magnetic tape was installed on an eight-mile stretch of MN TH7 between Hutchinson, MN and Silver Lake, MN and on a section of CR 7. The entirety of MN TH 7 between Hutchinson and I-494 was digitally mapped for use with the GPS system, as was CR 7.

A map of the MN TH7 corridor is shown in Figure 3.1 below.

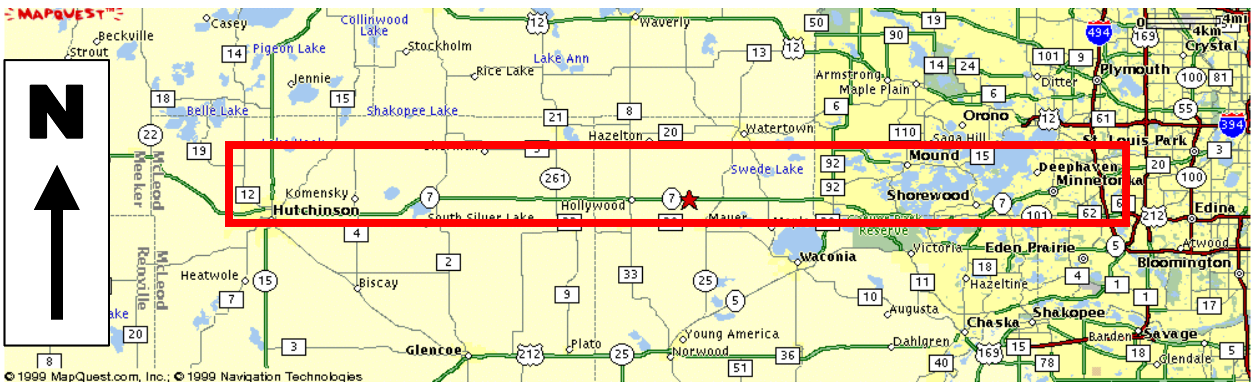


Figure 3.1. Map of the test corridor: State Highway 7

Drivers completed their routes as scheduled by Mn/DOT. This included experimental sessions with poor visibility and baseline sessions without poor visibility.

Visibility was determined from the weather station data, where the time at which the visibility distance was between the ranges of 300-399, 200-299, and 100-199 meters was recorded. Data in the visibility distance range of 100-199 meters was considered low-visibility.

PROCEDURE

Instructional Session

Operator training took three days (December 9th, 10th, and 11th, 2002). Classroom training instructed drivers on the operation and functionality of the DAS. This session also taught them how to answer the on-screen subjective questions presented at various points, as well as how to report comments and critical incidents. The consent form (Appendix A) was administered and a handbook (Appendix B) was given to each driver during the classroom training sessions. Afterwards, an in-vehicle training and familiarization session allowed them to get experience with the system.

Experimental Period

The experimental sessions lasted from December 23rd, 2002 through March 31st, 2003. An 'experimental session' is defined as any period of time where the plows are operating during low-visibility conditions, and where the driver uses the system traveling in one direction. 'Baseline sessions' are defined as operating periods without limited visibility, but with snow on the ground and road. 'Interview sessions' are times when the experimenter visited each station and asked the drivers a series of questions about using the system while driving.

MEASURES

Data were collected to measure Driving Performance (safety, productivity), Subjective Workload, and Usability measurements with the system activated and deactivated. Driving data was sampled at 10 Hz.

Driving Performance

Driving performance measures used for evaluation of the DAS were derived form the engineering data collected by the vehDAQ, sampled at a rate of 10 Hz.

The driving performance measures that were used for the evaluation are measures that could be influenced by the DAS. These measures were related to steering, speed, and lane departures.

Driver performance and productivity measures were derived from vehicle data collected with the vehDAQ.

Steering

Steering was continuously sampled through each direction of the route and thus for each condition. The vehDAQ collected steering wheel position directly from the vehicle in degrees from the center point, with negative values indicating steering to the left and positive values indicating steering to the right. The following measures were calculated based on these measures:

- Standard deviation of steering wheel position
- Mean of steering intervals – time intervals between steering wheel reversals

Speed

Speed was continuously sampled through each direction of the route and thus for each condition. The vehDAQ collected speed directly from the vehicle in Miles Per Hour. The following measures were calculated based on these measures:

- Mean and standard deviation of speed
- Maximum deceleration

Lane Position

Lane Position was continuously sampled through each direction of the route and thus for each condition. Vehicle lateral offset was collected directly from the vehicle by the vehDAQ in meters, and converted to feet for data analysis purposes. The center of the lane was considered to be a lateral offset of 0. Negative lane position values indicated that the truck was to the left of lane center and positive values indicated the truck was to the right of lane center. The following measures were calculated based on these measures:

- Mean and standard deviation of lane position
- Median and maximum exceedance time – duration from exit and return point of the tire relative to the lane boundary

- Median and maximum response time to a lane departure – time from leaving the lane to reaching the furthest distance outside of the lane
- Median and 85th percentile (used as maximum) of 1/TLC [Time to Line Crossing] – distance from outside sidewall of the tire to the nearest lane boundary divided by lateral speed

Many instances of 1/TLC may include temporarily driving outside of the lane boundaries. Since these instances may inflate 1/TLC, the median and 85th percentiles are used to decrease the likelihood of inflation occurring.

A truck was considered to be outside of the lane (i.e. a lane departure) when the outside sidewall of the tire crossed over the lane boundary.

Safety

An assessment of "critical incidents" was made to evaluate the safety effect of the system (based on Dingus et al., 2001). Collected data was analyzed for instances that are out of the ordinary, such as the following:

- Steering – wheel turned by driver faster than 3.64 radians/second.
- Lateral acceleration – lateral motion equal to or greater than 0.3g.
- Lane deviation – driver moved vehicle over the lane boundary.
- Time to collision – driver approaches object at rate equal or less than TTC = 4 seconds.
- Critical incident – driver indicated incident using panel button.

A data analyst validated instances using video recorded from the session to eliminate any false alarms from the analysis. An example of an invalid event would be a steering wheel turned faster than 3.64 rad/sec on a turn, or a lane deviation event due to plowing the shoulder of the road.

There is a distinction between two types of valid critical incidents:

- "Primary" critical incidents occur first in a sequence of incidents, are the only incident present, or are the direct cause of one or more incidents.
- "Secondary" critical indents follow another incident in a sequence, and are directly caused by the presence of one or more proceeding triggers

Data analysts determined whether each Primary Critical Incident was due to Driver Error (unplanned lane deviations, judgment error related to tailgating, etc.) or due to Another Driver (driver had no contribution to the incident). Analysts also classified incidents in terms of the following categories:

- Collision – any contact between the truck and any other fixed or moving object, animal, or pedestrian.
- Near Collision – a critical incident involving moving vehicles or a situation of very close speed/distance proximity between the truck and any other fixed or moving object, animal, or pedestrian that required a rapid, evasive maneuver to avoid a crash.

- Hazard Present – a critical incident in close proximity to another vehicle or fixed or moving object, animal, or pedestrian that *did not* require a rapid evasive maneuver to avoid a crash. These also include driver-indicated incidents using the panel button.
- No Hazard Present – a critical incident where there was not close proximity to another vehicle or fixed or moving object, animal, or pedestrian.

The number of incidents may also be examined in relation to the time of day, number per hour, number per driver error, or number per hours driven by that driver.

Productivity

Since no clear productivity measure could be used due to the nature of plowing routes and the geographic limitations of our system, productivity could only be measured in the following ways:

- Speed of driving
- Stability and safety in lane keeping (lane position variables)

Subjective Mental Workload

Regular system prompting was used to get standard information from the driver at fixed points and times so that comparisons could be made with and without the system. This was planned to provide regular subjective data to compare the system with unassisted driving. The system prompted the drivers to answer a set of questions after driving past predetermined midpoints for both directions of the operational route. At each point, a tone signaled to the driver that they were to answer the questions presented on the touch panel. These questions relate to the overall response of the driver to the driving conditions and system performance. They do not provide direct comment about the system itself.

These items were based on a standard measure of mental workload (NASA-RTLX), but converted to a five-point scale to simplify the response input (Appendix D). Definitions and instructions were given to drivers in advance, during the training session. There were two panels displayed in series. Each panel had three questions from the above list. Each panel closed when the ‘done’ button was pressed, or after five minutes elapsed. This gave the option for the driver to exit without completing to return to the system display.

Usability

The vehDAQ recorded the status of each DAS system component and drivers were given the ability to adjust (and turn off) components at any time. This included turning on/off the HUD, as well as the seat and audio lateral warnings. This also included adjusting the volume of warning sounds and adjusting the system’s reported offset from center of lane. This data was used with the record of prevailing weather conditions to derive inferred measures of acceptability, usage, and desirability by comparing the amount of time each component is selected (relative to the visibility conditions).

Driver Initiated Comments

The touch screen panel featured “Comment” and “Event” buttons (Figure 3.2). The driver was told that they could activate the Comment button when they wanted to report about the system or any comments they may have in general. This button was a blue circle, labeled "Comment." It flagged the data file so that the data could be examined in detail. At the time the comment button was activated, a panel also appeared with two (or three) questions that the driver is invited to answer. This process was intended to collect open-ended verbal comments that the driver determines are important, as well as at least two standard questions that are then measured during the actual driving situation. The questions pertained to the driver's level of 'Effort', 'Safety', and system 'Usefulness' when the system is active, and the level of 'Effort' and 'Safety' when the system was inactive.

There was a need for an additional driver input button for denoting safety critical events, such as incidents with other traffic. This button was a hazard triangle with a "!" in the center, labeled "Event," and was larger than the adjacent comment button. This button logged the event time and drivers were instructed to give a verbal explanation of why they chose to hit the Event button.

Examples of this interface are shown below:

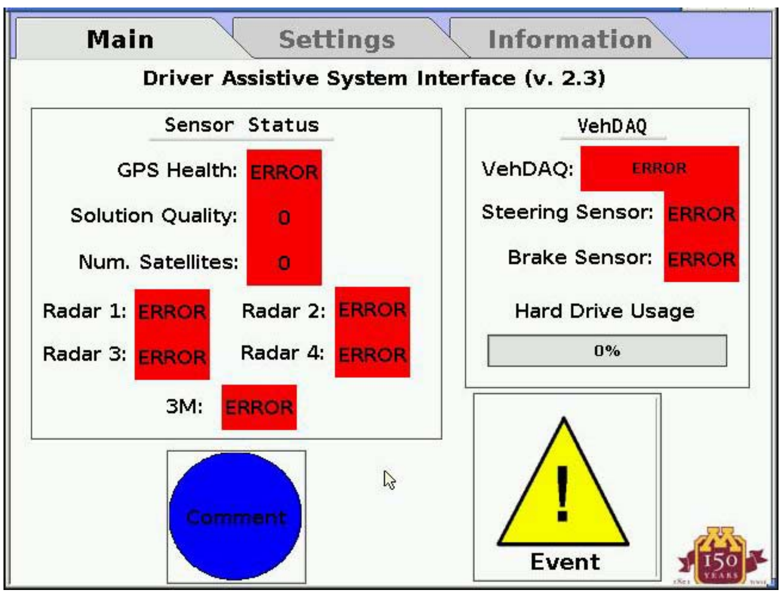


Figure 3.2. Touch Screen Interface, with 'Comment' and 'Event' buttons

This driver-initiated data was intended to provide important insights into the spontaneous reaction of the driver to the system during operations. However, because it is dependent on the driver to initiate the data collection process, there was the risk that no data will be submitted. There is also no control over when or where the data is collected which could undermine the analysis.

End of Session

On-screen questionnaires, system-prompted upon return to their station, were used to gather the drivers' opinions of the system soon after using it. As the plow entered the station area, the touch screen panel switched to this questionnaire series and a verbal reminder was played over the speaker system. Here, a very simple measure of usability was used in terms of the driver's satisfaction with the system and perceived usefulness (Appendix E). The driver was parked to complete this series of questions.

The format was similar to previous reporting with five response buttons, but the scales were anchored by antonyms (good-bad) rather than levels of the construct (low-high). There were three panels of three items, and each panel was closed when the 'done' button was pressed.

Although using the panel can provide data in the immediate context of use, the simplified method of response input limits the extent of information that can be collected. To get more information from the driver about the overall experience with the system, it was necessary to also conduct structure interviews and debriefing questionnaires.

Final Survey

Perceived usability, acceptance, system reliability, safety, and acceptance of the system were measured by a survey questionnaire completed by drivers after the study was completed (Appendix G). This was completed after the track testing of the system (see below), since it was not believed that the drivers had enough experience with the system under the proper conditions during the FOT. Though the survey asked the same survey questions as last year's FOT, the questions were more clearly formatted and reworded. Results from last year's survey only pertained to baseline conditions. Therefore, results of the two surveys were be compared to see if attitudes about the system improve after using the system during weather conditions in which it was intended to be used.

Interviews

On January 22, February 19, and in March, 2003, an experimenter visited each of the stations for interview sessions. These were used to examine issues pertaining to usability, acceptance, inherent safety issues, and effectiveness of training. During the interview, the experimenter sat down in private with each driver who had used the system and asked them to rate their agreement or disagreement with statements relating to their experience with the system. The full list of questions can be found in Appendix F. Drivers rated their agreement on a scale from one (Strongly Disagree) to five (Strongly Agree). Some questions had open-ended follow-ups to glean further information. Their answers were recorded and compiled by the experimenter.

ANALYSIS

Data measures were analyzed in respect to the following comparisons:

- **System Effect –** Comparing "system on" during poor visibility to "system off" during poor visibility
- **Baseline Comparison –** Comparing system on during poor visibility to system off under good visibility

4 RESULTS: FIELD OPERATIONAL TESTING

EXCLUDED RESULTS

As was the case during the winter of 2002, this winter had relatively mild and precipitation-free weather. This is unfortunate since the purpose of the FOT was to determine whether using the DAS enhanced the performance of specialty vehicle operators when they faced conditions of limited visibility.

During the winter there were several occasions when it did snow. Six meteorological sites recorded local atmospheric visibility measurements at five-minute intervals throughout the FOT. The sites were situated between five and twelve miles apart along MN TH-7. However, during the days in which plow drivers were out clearing the roads, weather conditions were predominately clear. Figure 4.1 shows the percentage of time that the weather stations measured snow, rain, or no precipitation for these days. Throughout the season, high winds and blowing snow were only reported on rare occasions.

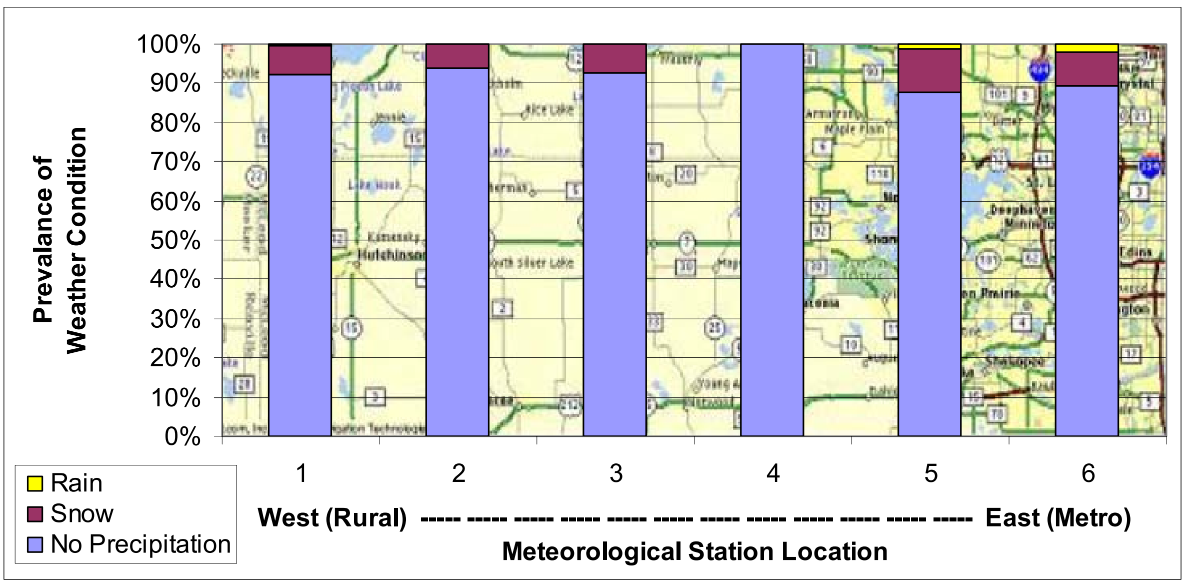


Figure 4.1. Meteorological data from six local sites on State Highway 7, during days in which drivers were out clearing roads between December 23, 2002 and March 31, 2003.

During the FOT, this lack of low-visibility conditions was noted and discussed by the researchers and Mn/DOT. Since conditions were not expected to "improve" (i.e. low-visibility weather conditions were not expected), it was decided that a track testing of the DAS would be conducted, as explained below.

Further, it was decided that there is not enough data from the FOT to make reasonable conclusions about most of the driver performance measures. These measures were instead gleaned from the track testing, where more controlled analyses were performed. The Post-Season Survey was given during the track testing, instead of after the FOT. However, since it is concerned with both with the system experiences (FOT and Track Testing), it is discussed later in this document. Data collected from the remaining FOT measures were analyzed, including:

- Usability (Driver Initiated Comments)
- Interviews

RESULTS FRAMEWORK OVERVIEW

Table 4.1 presents an overview of the results according to the framework objective they pertain to.

	Driver Initiated Comments	Interviews - Scaled Responses	Interviews - Open-Ended Questions
Operability		• Remembering how to use the DAS was difficult	• What have you learned from using the DAS that you should have been told before using it?
Safety		• Using the DAS made me feel safer • The DAS distracted me very much • Using the DAS made me a safer driver	• In what ways did using the DAS make you a safer driver?
Acceptance - Trust	• Comments • Events	• I felt more comfortable while using the DAS • I often relied on the DAS for guidance in maintaining lane position • I had confidence that the DAS would help me maintain my lane position • I trusted the DAS to help me maintain lane position, as compared to trusting my own abilities	• If you had trouble trusting the DAS, what were your reasons for this?
Acceptance - Usability		• Using the DAS while driving took a lot of effort • The DAS was useful in good visibility • The DAS was useful in poor visibility • Using the DAS improved my plowing performance • The DAS provided useful information in addition to my traditional visual cues • It was easier to drive while using the DAS • I was satisfied with the overall performance of the DAS	• In what ways did using the DAS improve your plowing performance?
Reliability		• The DAS provided me with reliable information • I trusted the DAS to provide me with accurate information	• What was most useful to you/what would be your ideal configuration of the DAS? • What parts of the DAS should be *removed*? • What things would you like *added* to improve the DAS?

Table 4.1. Overview of questions presented in FOT Results, by framework objective.

USABILITY – DRIVER INITIATED COMMENTS

A count of the Comments that the drivers indicated while driving were compiled and sorted by the system component they pertained to. They were then sorted by whether the comment related to the information content or reliability of the system component (Table 4.2).

Component	Reliability	Content	Other	Total
GPS	5	0	0	5
HUD	0	1	0	1
Radar	1	0	0	1

Table 4.2. Count of driver initiated comments and events

Most comments related to the reliability of the GPS fix, and this was also the case from the interview data (see below). Radar was also noted as a reliability problem in terms of not catching all of the visible targets, including cars directly in front of the driver. The only content comment was that a portion of guardrail was not mapped in the HUD.

Some examples of the reported comments are listed in Table 4.3.

Comments:	Count:
"No GPS" / "Solution from here is really bad today, something's wrong"	5
"Radar is still dropping out, it's not constant for the car I am following"	2
"I'm a little off by 3 feet. The solution is 5, I don't know what's wrong with it"	1
"Guard rail here is not marked on the right"	1

Table 4.3. Count of driver comments

Drivers were also required to report Events that related to the handling of the plow or incidents with traffic hazards as shown in Table 4.4. Just as with Comments, there were (fortunately) not many Events noted, but the ones that were noted were to tell us that the driver had knowingly stopped or moved out of the lane.

Event:	Count:
Plowing shoulder	2
Pulled over to let cars pass	2
The driver stopped to help out with an accident	1
Hits the button before wiping off mirror	1
(Unknown)	3

Table 4.4. Count of types of driver-initiated event

Overall, this driver-reported data was not plentiful. Possibly the drivers did not have much to report, or they did not accept the reporting task itself. (Several comments were made by drivers that the questions that came up mid route, the audio files that notified drivers of specific tasks, and the questions that appeared after hitting the comment button were distracting to their driving. Though this was the design of our experiment, such feelings towards these elements may have caused the drivers to be less enthusiastic about answering said questions or participating in hitting the Comment and Event buttons. Because of this, opinions of these elements should be separated from suggestions and thoughts about the system itself.)

Drivers wanted to be helpful to the researchers and at times noted when they were plowing the shoulder, wiping off their mirrors, or parked in the shoulder to let cars pass or help other vehicles in need. None of these events reflect a true “Event” as we had intended it, but they are useful to note nonetheless since they indicate that drivers regularly plow or park in the shoulder for various reasons. Because of this it is important to allow them the option to turn the system warnings off temporarily to perform these actions when the truck remains running.

Driver Initiated Comments Summary and Conclusions

The most prevalent complaint was that the GPS fix was lost, or was non-existent for a certain period of time. Since this is the heart of the DAS, when this happened it was apparent to the drivers, and therefore it was expected to be the element most commented about. The best preventative measure that is suggested from these comments would be to implement methods in which to alert drivers when a loss of GPS signal is about to occur. However, it is unclear from these sparse comments if there was a pattern to when these drop outs of GPS coverage occurred. This is unfortunate, since it is often factors external to the DAS that cause GPS signal disruption. Learning what was causing these disruptions would help in making future iterations of the DAS more robust.

Though specifically regarding the GPS coverage, the comment about the system being off by three feet is more of a training issue since a solution of five indicates a “floating” quality of GPS signal. This means that the results will not have the same accuracy as if the system had a true fix. Though this was explained during training, it is understandable why the driver made this comment. A recommendation here would be to make the system status as simple to understand as possible, and instead of making the drivers learn a new number system, simply state on the display screen “fix”, “float”, etc. in terms they can understand and interpret quickly.

Radar was the second most commented item, with one driver noting twice that the radar was not constant for the cars he was following at those times. This may have been an issue due to limitations in radar technology to date. For example, the radar does not pick up targets moving at less than a quarter of a mph, which means that while the truck is moving, warnings for vehicles traveling at the same speed might appear to “flicker” on and off. Though these vehicles would be picked up if they suddenly slowed or sped up, it would appear to the drivers that the system is being inconsistent. This seemed to be the case with our drivers.

The unmarked guardrail reported by the drivers is a mapping issue. Though this piece of furniture may have been added after the mapping was completed, it seems to be confusing for the drivers to see some objects mapped in the HUD and have others show up with the radar. It is recommended that all objects be mapped and maintained regularly for changes on the road, or that none of these objects are mapped. Either solution ensures that consistency is maintained throughout the system.

Giving drivers consistent and useful warnings should be a top priority of the radar function. Even though it was technically performing properly, drivers thought its performance was inconsistent. For current versions, it is recommended that training include an explanation of why it is functioning in this manner. Future versions should look to other creative solutions and improvements in target detection technology to help with the unmapped furniture and "flickering" issues that seem to hurt the overall trust and understandability of the radar function.

INTERVIEWS

Below are the compiled interview responses from the three interview sessions. The graphs and analyses of the scaled responses are presented first, followed by open-ended comments. The reader should keep in mind that the poor weather of this season limited the full generalization of these opinions to true heavy winter low-visibility conditions. Also, based on the small number (seven) of drivers interviewed, the power of the results is low [power = {0.058 to 0.358}, except for question 10 where power = .633]. Therefore, the trends that were not found to be statistically significant should be interpreted with caution.

The results are organized in the framework of the objectives previously stated (Figure 2.1). These objectives are:

- Operability: These questions refer to how well the drivers could learn and remember how to use the system.
- Safety: Drivers were asked how well they felt the system reduced their risk of encountering hazardous situations and crashing.
- Acceptance: Drivers were asked if they liked how the system performed, if it helped them drive and plow, and whether they would use it in a normal operations. For clarity, the acceptance- related questions are divided into questions relating to Trust in the system and questions relating to Usability of the system.
- Reliability: These questions dealt with the sustainability and dependability of the system over time.

Scaled Responses

Drivers were asked to report the degree of agreement they had with a number of statements about the usability of the system and its impact on the driving experience including plowing performance. Drivers rated their agreement on this scale: 1 = Strongly Disagree; 2 = Disagree; 3 = No Opinion; 4 = Agree; and 5 = Strongly Agree.

Each driver's response is graphed so as to show trends by each interview period (Experience) as well as by each station (Geographic). If two drivers at the same station respond similarly, their icons will overlap, such as with the Hutchinson drivers in Interview Period 3 of Figure 4.2. Portions of the concealed icon are visible around the concealing icon. The means of the responses in each period are also presented.

From these results, the following trends are reported:

Experience: Trends by interview session show how opinions of the system changed over time, and thus show how opinions changed with system experience. Comparing the means of the data from interview sessions 1, 2, and 3 will show these experience-based trends (highlighted in Figure 4.2).

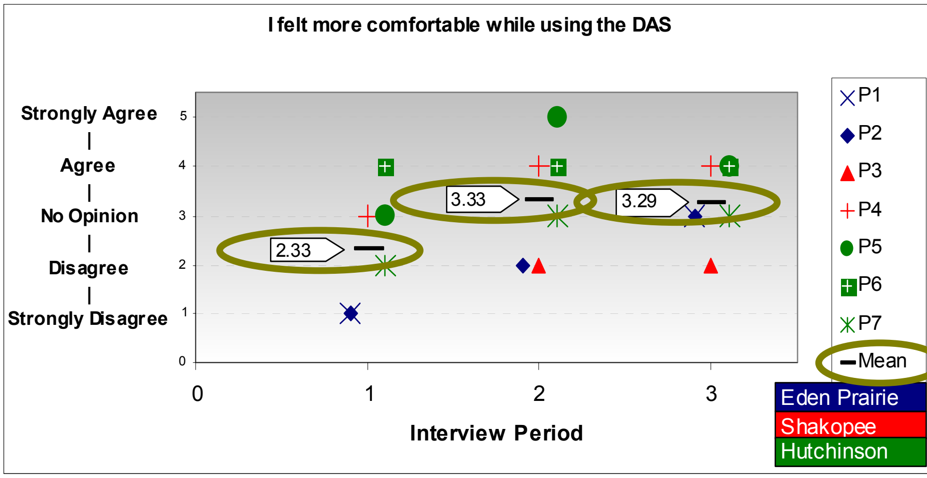


Figure 4.2. e.g. Experience Trends.

These means were tested for statistical significance using non-parametric tests (Friedman). All cases of statistical significance are reported starting with the test that was performed (F_{CS}), followed by the alpha level of significance (p). If a question was significant, this implies that the differences in the means between the three interview periods for that question are reliably different, and thus show a trend due to experience.

It is also important to note that there was no snow before the first interview, so impressions gathered there are based on experience with the system only in good visibility conditions. Therefore, differences in opinion before (Interview 1) and after exposure to snow (Interviews 2 and 3) confound experience with the system in general with the opportunity to use the system under low-visibility conditions for which it was designed.

Geographic: Trends by station show how plowing in different geographic locations affects the driver's opinion of the system. Comparing the colors of the blue, red, and green data icons show these trends (highlighted in Figure 4.3).

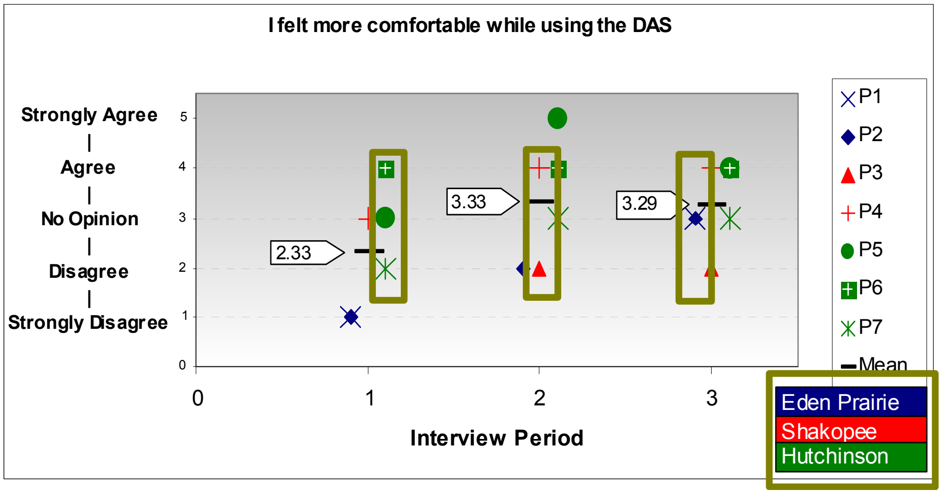


Figure 4.3. e.g. Geographic Trends.

Though trends are reported, testing for statistical significance was not conducted. This is because there were only two drivers for two of the stations, and this is not a high enough number of drivers to make a meaningful analysis. Responses were grouped according to agreement (5 and 4) or disagreement (2 and 1) with the statement, with the No Opinion (3) responses grouped with the less favorable outcome of the question. For example, in Figure 4.3 for Interview Period 2, three drivers agreed feeling more comfortable while using the DAS, while the other three drivers (including the one that rated 'No Opinion') disagreed.

- The Hutchinson station (HATS) drivers consisted of Hutchinson city and McLeod county drivers. HATS is considered to be a 'rural' test route on Highway 7 (green icons in the plots and green highlighted portion of the route in Figure 4.4). As such, HATS station will be referred to in this report as a 'rural area.' This route begins in the city of Hutchinson and goes east to Highway 25, and includes the portion of County Road 7 that McLeod County drivers drove (black highlighted portion of Figure 4.4). This route is the furthest from the Minneapolis metro area and this section of the test route is one lane in each direction, is mostly unlit, and has no barriers or curbs to aid in navigating the route in poor visibility conditions. Streetlights are present only in the city of Hutchinson.

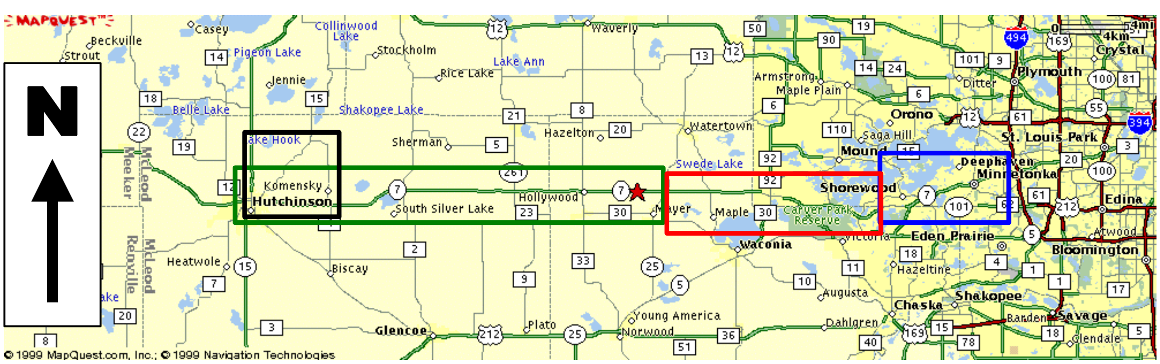


Figure 4.4. Map and diagram of the station routes on the Highway 7 test corridor

- Though Shakopee station (red icons in the plots and red highlighted portion of the route in Figure 4.4) is geographically closer to the city, its section of Highway 7 should also be thought of as 'rural' in nature, and will be referred to in this report as a 'near-rural area.' This route on Highway 7 begins at Highway 25 and goes east to Highway 41. This route is mostly 1 lane in each direction, unlit, has no barriers or curbs to aid in navigating the route in poor visibility conditions. Streetlights and curbs are present in portions closer to the Minneapolis metro area, such as when the highway passes through the city of St. Bonifacius and at major intersections.

- The Eden Prairie station is considered to be in the 'metro' area on Highway 7 (blue icons in the plots and blue highlighted portion of the route in Figure 4.4) and will be referred to in this report as a 'metro area.' This route on Highway 7 begins at Highway 41 and goes east to I-494. This route is comprised of two lanes in each direction and has constant street lighting as well as frequent jersey barriers and curbs to aid them in poor visibility conditions. It should be noted that the Eden Prairie drivers admitted to frequently turning off most (if not all) parts of the system and only having used the full system during the instructional session. Their claim for doing this was related to their geography; since they were so close to the metro area, they did not feel they needed assistance due to good lighting conditions and the presence of jersey barriers and curbs. Because of this, more focus is placed on the drivers from the other two stations.

Overall: Since the third interview represents the drivers' experience with the system after a three-month period, emphasis is placed on the third and final interview to give an overall impression of system rating for each measure (highlighted in Figure 4.5).

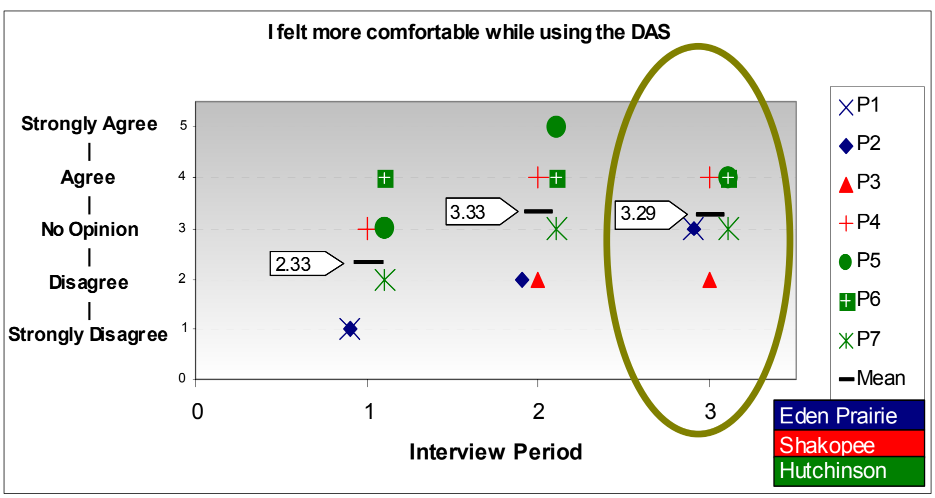


Figure 4.5. e.g. Overall Trends.

This provides data about driver opinion based on the maximum experience with the system in the operational context. Though trends are reported, testing for statistical significance was not conducted. Responses were grouped according to agreement (5 and 4) or disagreement (2 and 1) with the statement, with the No Opinion (3) responses grouped with the less favorable outcome of the question. For example, in Figure 4.5 for Interview Period 2, three drivers agreed that they felt more comfortable while using the DAS, while the other three drivers (including the one that rated 'No Opinion') disagreed.

Operability

Drivers were asked to indicate the level of (dis)agreement with the statement, "Remembering how to use the DAS was difficult" as a measure of perceived system operability.

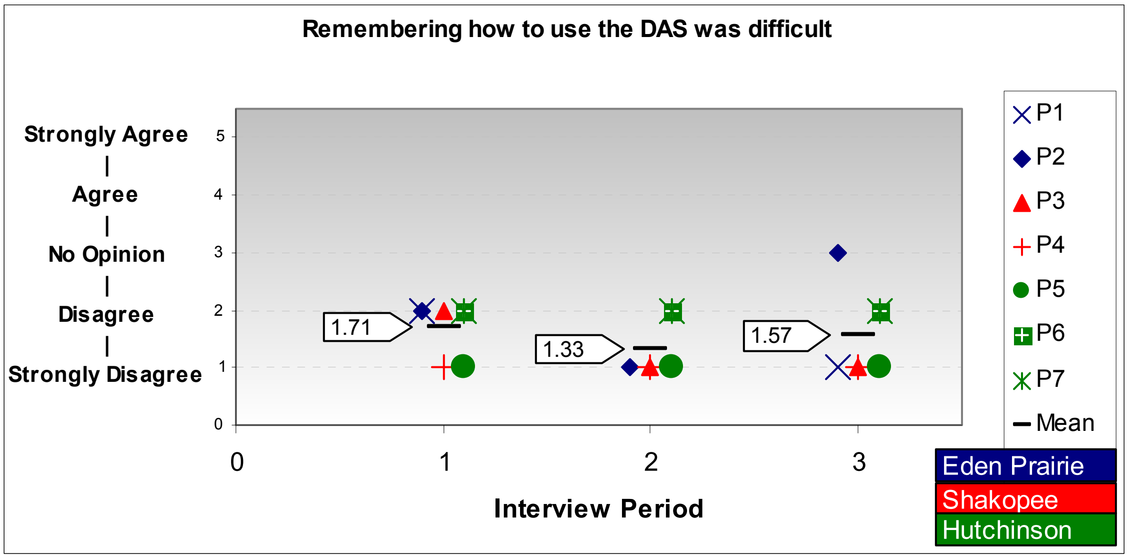


Figure 4.6. Interview data for statement "Remembering how to use the DAS was difficult".

This question was purposely posed in a reverse manner, and trends reported below relate to how it was originally posed.

Experience: All drivers were consistent throughout the study in disagreeing that "Remembering how to use the DAS was difficult." Both before and after experience with snow, all drivers (save one) disagreed that remembering to us the system was difficult. This suggests that once drivers are instructed on how to use the system, they are confident that they will remember how to use it. Though these trends based on experience were not significant, this merely means that drivers thought it was easy to remember how to use the DAS from the beginning, and experience did not change this opinion.

Geographic: Since drivers from all areas disagreed that remembering how to use the system was difficult, there are no clear differences due to geographic region. This suggests that using the system in different weather and road types has no effect on remembering how to use the system.

Overall: All drivers, except one with 'no opinion,' disagreed that remembering how to use the system was difficult. It also seems that neither experience, experience with snow, nor geography affected drivers agreement to remembering how to use the system, implying that after being trained on how to use the system, it is easy to remember how it functions.

Operability Summary
Remembering how to use the system did not seem to be a problem for these drivers, especially after having used the system in some low-visibility conditions. This also suggests that the training presented to the drivers was adequate and sufficient to help them remember how to use this version of the system.

Safety
Drivers were asked to indicate the level of (dis)agreement with the statement, "Using the DAS made me feel safer" as a measure of perceived system safety.

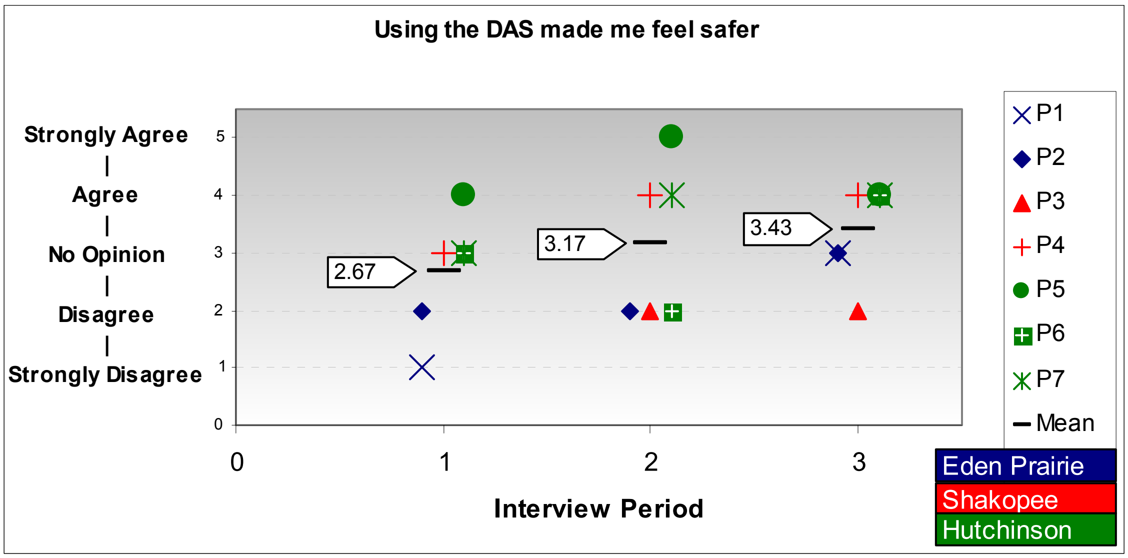


Figure 4.7. Interview data for statement "Using the DAS made me feel safer."

Experience: With experience came a stronger impression that the system helped with safety. The more experience they had with it, the more drivers agreed that the system made them feel safer, especially after seeing how the system could help them in snow events. However, these trends based on experience were not significant.

Geographic: The rural area drivers reported feeling safer while using the system than the metro and near-rural areas did. By the third interview, all three rural drivers agreed that the system made them feel safer while both near-rural and metro drivers did not agree.

Overall: Interview 3 shows that the drivers came to find a safety benefit in the system by the season's end. The majority of drivers (4 / 7) agreed to feeling safer while using it. This shows that using the system helped drivers see a safety benefit and that more drivers felt safer the longer they used it.

Drivers were asked to indicate the level of (dis)agreement with the statement "The DAS distracted me very much" as a measure of perceived system safety.

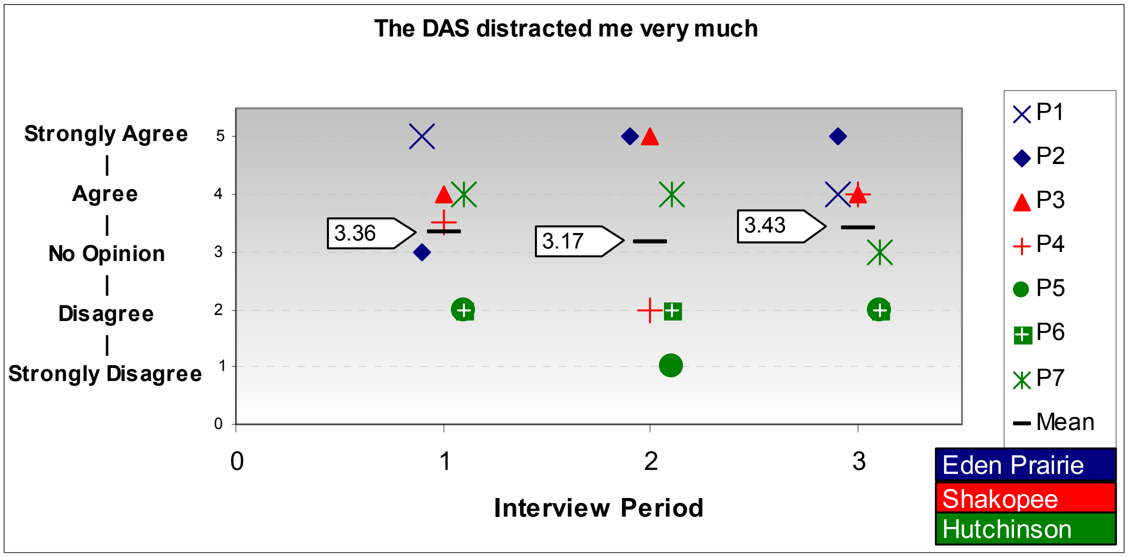


Figure 4.8. Interview data for statement "The DAS distracted me very much."

Experience: Experience did not seem to affect the drivers' lack of opinion on the distraction of the system, though their scores tended to lean towards agreeing that the DAS distracted them. However, opinions differed greatly and also varied geographically, though the average rating from each interview period was comparable both before and after experiencing snow events. Overall, these trends based on experience were not significant.

Geographic: The rural drivers tended to disagree (5 / 8 responses) that the DAS was distracting while the near-rural and metro areas almost always agreed (9 / 11 responses). The scores in Interview 2 were highly mixed possibly due to having more experience using the system in low-visibility conditions.

Overall: Though the average for Interview 3 leans towards agreement that the DAS distracted drivers, the scores are divided sharply by geography. Two rural drivers said the system was not distracting (one had 'no opinion'), while all metro and near-rural drivers agreed that the system was distracting. This shows that drivers in areas where the system is most beneficial (rural) did not find the system distracting while mixed areas (near-rural) found the distraction of using the system to outweigh the benefits it provided.

Drivers were asked to indicate the level of (dis)agreement with the statement "Using the DAS made me a safer driver" as a measure of perceived system safety.

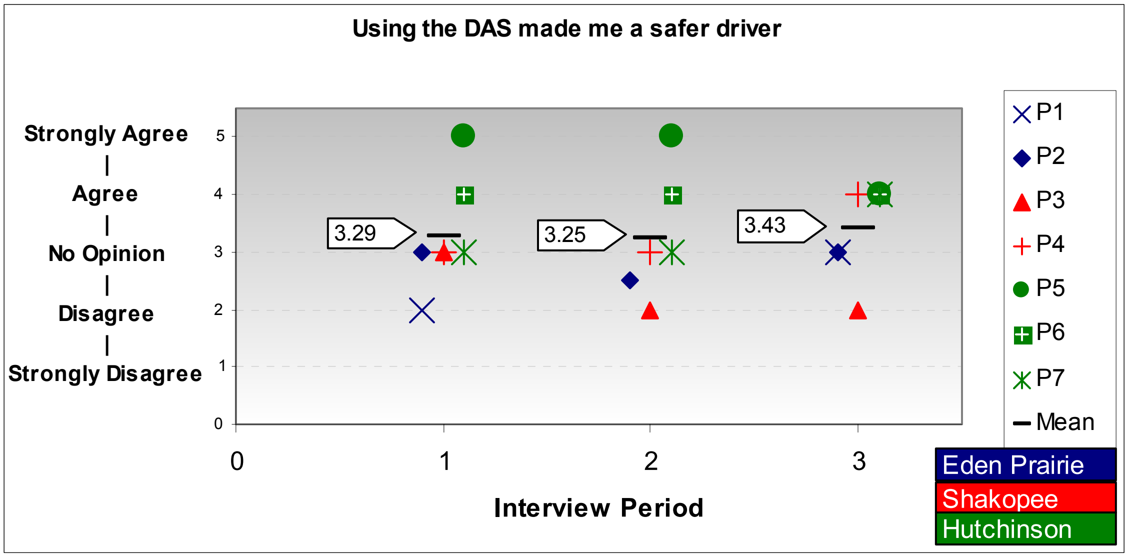


Figure 4.9. Interview data for statement "Using the DAS made me a safer driver."

Experience: Initially drivers had a consistent 'no opinion' rating that the DAS made them feel safer. After experiencing snow, Interview 2 showed a similar 'no opinion' rating. By Interview 3, four out of seven drivers agreed that using the system made them a safer driver. In this instance, it seems that it is not snow but experience with using the system in snow that raised drivers agreement that that the system made them feel safer. However, these trends based on experience were not significant.

Geographic: Drivers in more rural areas felt strongly that using the DAS made them a safer driver than the drivers in metro and near-rural areas. Seven out of nine responses of rural drivers (over all the interviews) were in agreement that the system made them safer. On the other hand, only one near-rural or urban driver response agreed (1 / 11 responses). Rural drivers may have felt safer and found the DAS more beneficial since they experienced more blowing snow and unlit conditions.

Overall: Overall drivers slightly agreed that the system made them safer drivers, with more than half agreeing to trust the system and two out of the remaining three stating 'no opinion.' Rural drivers' average was in agreement that the DAS made them feel safer, while both other stations had 'no opinion' on feeling safer. This overall average is slightly encouraging, since it suggests finding feelings of safety at least in the rural areas.

Safety Summary

Though drivers found the system somewhat distracting when asked directly, intrinsic safety benefits of the system are present as evident by their responses that the system made them feel safer and feel that they had more control while driving. Geographically, more rural drivers felt safer using the system, and this could be the result of less traffic and/or visual cues during their routes.

Acceptance

Acceptance – Trust

Drivers were asked to indicate the level of (dis)agreement with the statement "I felt more comfortable while using the DAS" as a measure of perceived acceptance of the system.

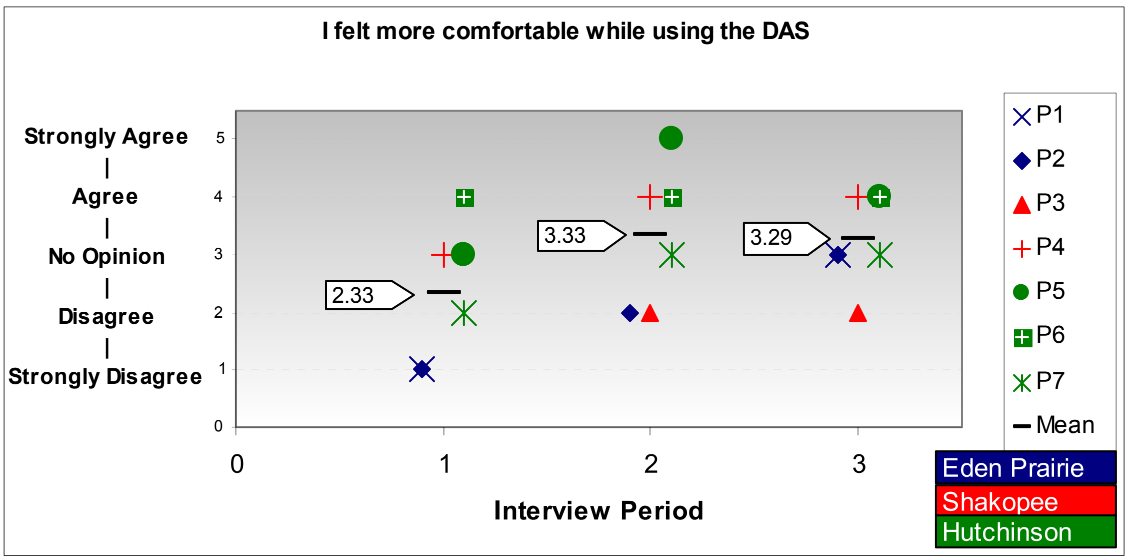


Figure 4.10. Interview data for statement "I felt more comfortable while using the DAS."

Experience: Initially it seemed that the drivers were not comfortable using the system, but over time they grew more comfortable and reported no opinion on their comfort level while using the DAS. This result due to experience was significant, $\underline{F}_{CS}$ (5) = 6.86, $\underline{p}$ = .032. Snow appears to be an influential factor, since their opinions changed from uncomfortable in Interview 1 to 'no opinion' (yet slightly comfortable) in Interviews 2 and 3 after the season produced more snow events.

Geographic: The rural and near-rural areas reported being more comfortable using the system than the metro. On average, rural drivers reported being more comfortable than near-rural drivers, possibly due to having more experience using the system in low-visibility conditions.

Overall: After the full period of exposure with the system, all drivers except one agreed that they were either comfortable while using the DAS or had 'no opinion.' Rural area drivers showed a slightly higher level of comfort than the other two areas. This shows that all drivers were not completely comfortable using the system while driving.

Drivers were asked to indicate the level of (dis)agreement with the statement, "I often relied on the DAS for guidance in maintaining lane position" as a measure of perceived acceptance of the system.

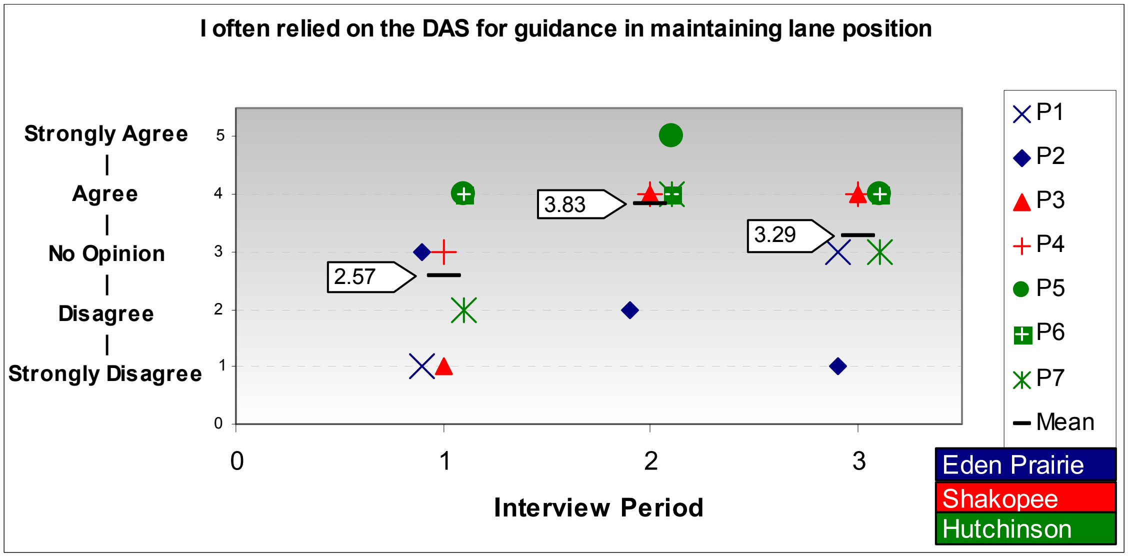


Figure 4.11. Interview data for statement "I often relied on the DAS for guidance in maintaining lane position."

Experience: Before drivers experienced the system, many tended to have 'no opinion' or disagreed that they relied on the system for guidance in maintaining lane position. After experiencing snowy weather, however, they seemed to agree that they could rely on the system for guidance. This rise in agreement could be due to more exposure to the system in poor visibility conditions, or just more exposure to the system in general. Even though their reliance rating dropped by the third interview period, a majority of drivers still felt they could rely on the system for guidance, though overall these trends were not significant.

Geographic: Throughout the interview periods, the rural and near-rural drivers reported a much higher agreement in relying on the system for guidance than the metro drivers. Especially after experiencing lower visibility conditions, rural and near-rural drivers agreed (11 / 15 responses) that they could rely on the system for guidance in maintaining lane position,

Overall: Three out of seven drivers still disagreed that they could rely on the DAS for guidance in maintaining lane position by the end of the season. Four out of five rural and near-rural area drivers reported they could rely on it for guidance, the fifth reporting 'no opinion.' This suggests that after having time to see what the system offers, especially in rural snow conditions, the drivers could rely on the system to keep them in their lane.

Drivers were asked to indicate the level of (dis)agreement with the statement, "I had confidence that the DAS would help me maintain my lane position" as a measure of perceived acceptance of the system.

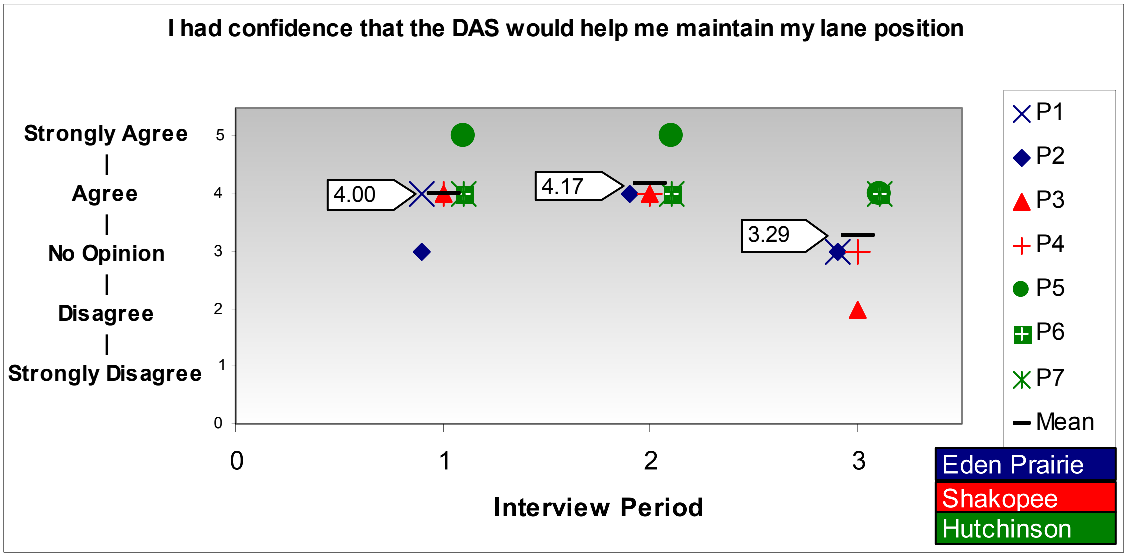


Figure 4.12. Interview data for statement "I had confidence that the DAS would help me maintain my lane position."

Experience: Initially drivers seemed to have a high and consistent confidence that the DAS would help them maintain their lane position, and this agreement was maintained after the year's first few snow conditions (Interview 2). However, their opinion dramatically drops close to 'no opinion' by the end of the season. This result due to experience was significant, $\underline{F}_{CS}$ (5) = 6.50, $\underline{p}$ = .039. In this instance, it seems that it is not snow but experience with using the system in snow that drops drivers confidence that the system would help them stay in their lane.

Geographic: Initially drivers from all stations agreed that they had confidence in the system helping them maintain lane position. The rural area drivers maintained this opinion through the final interview, however both metro and near-rural drivers' confidence dropped more by the end of the season (3 / 4 to 'no opinion'). This may show that the system is more consistent in helping drivers maintain lane position in rural areas where snow is known to blow and drift than in other areas.

Overall: Drivers ended up being split geographically on their confidence that the system helped them maintain lane position or not, leaving an overall mean close to 'no opinion.' This split consisted of the rural drivers having confidence that it did help while near-rural and metro mostly had 'no opinion' (one did not have confidence) that the system would help them maintain lane position. This shows that confidence in the system was strongly influenced by the weather and geographic conditions.

Drivers were asked to indicate the level of (dis)agreement with the statement, "I trusted the DAS to help me maintain lane position, as compared to trusting my own abilities" as a measure of perceived acceptance of the system.

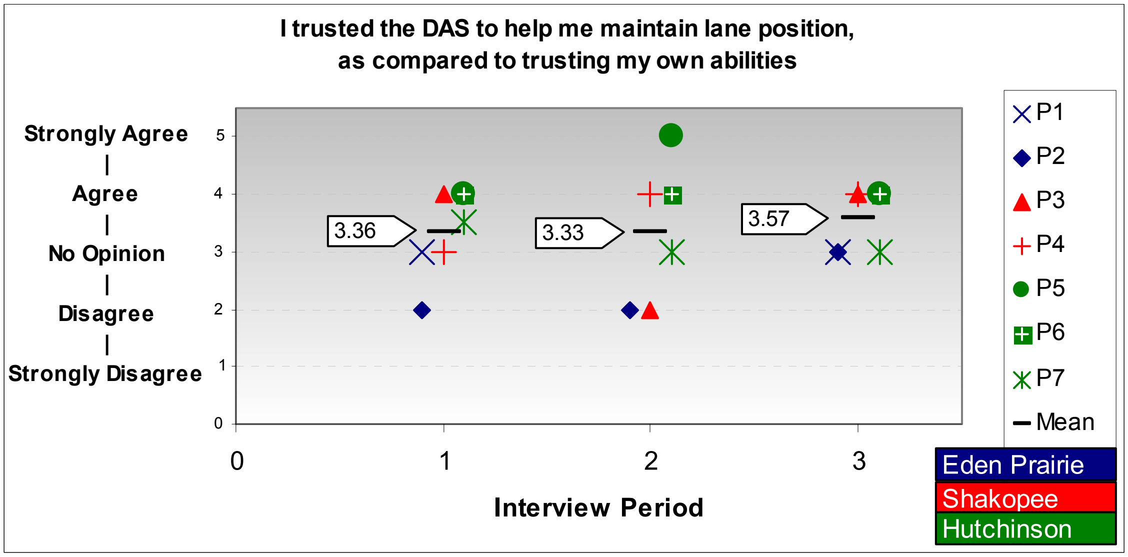


Figure 4.13. Interview data for statement "I trusted the DAS to help me maintain lane position, as compared to trusting my own abilities."

Experience: Initially drivers had 'no opinion' whether the DAS would help them maintain lane position, as compared to trusting their own abilities. After experiencing snow, Interview 2 showed a similar 'no opinion' rating, only with more varying scores. By Interview 4, four out of seven drivers agreed that the system helped maintain lane position, the other three having 'no opinion.' In this instance, it seems that it is not snow but experience with using the system in snow that raised drivers' trust that the system would help them stay in their lane, though these trends based on experience were not significant.

Geographic: It seems that rural and near-rural drivers trusted the system to help them maintain lane position (11 / 15 responses). On average, rural drivers were in agreement in trusting the DAS throughout the interviews. Near-rural drivers, on the other hand, first slightly agreed, then split their opinions by Interview 2 and finally both agreed to trusting the system by the end of the season. Rural and near-rural drivers may have found more benefit in trusting the DAS to help them maintain lane position, since they experienced some blowing snow and unlit conditions.

Overall: Overall, drivers did agree that they trusted the system, with more than half (four) agreeing to trusting the system and three stating 'no opinion'. Both rural and near-rural stations average in the agreement to trusting the system, showing that rural drivers trusted the system to help them maintain lane position, as compared to trusting their own abilities.

Acceptance – Trust Summary

It seemed that experience with the system increased drivers' trust that it would function as they expected it to. Initially their trust in the DAS was low, and though their trust increased by the end of the season it peaked just above 'no opinion.' This suggests that some work is needed to harden the system and improve drivers' trust in it. The geographic location of the drivers' route, and thus the visibility conditions they experienced, played a role in their trust. Drivers in the rural and near-rural areas trusted the system more than metro area drivers, probably due to having more need for such a system and a greater number of opportunities to use it.

Acceptance – Usability

Drivers were asked to indicate the level of (dis)agreement with the statement "Using the DAS while driving took a lot of effort" as a measure of perceived acceptance of the system.

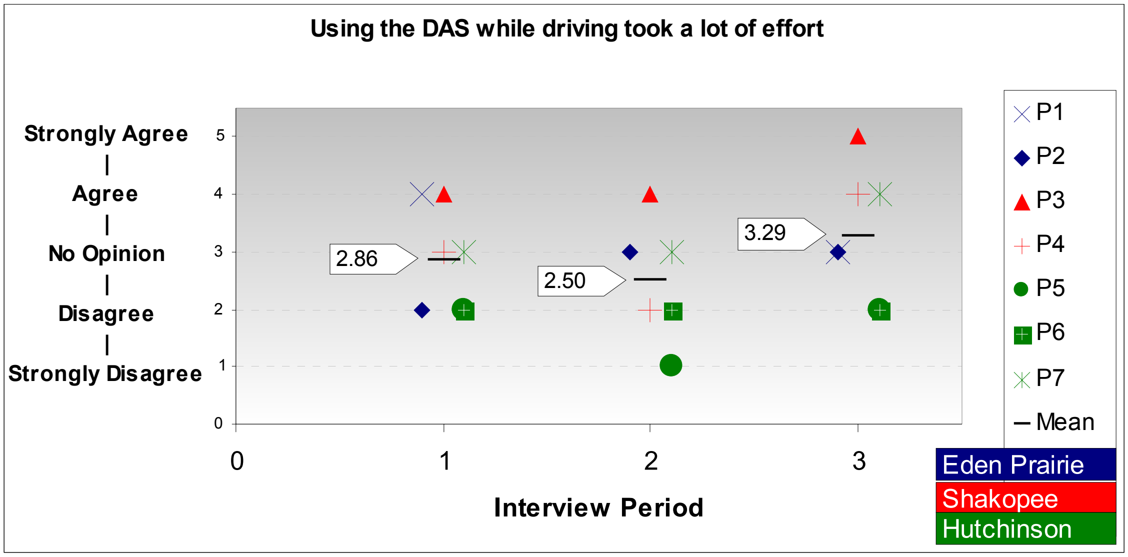


Figure 4.14. Interview data for statement "Using the DAS while driving took a lot of effort".

This question was purposely posed in a reverse manner, and trends reported below relate to how it was originally posed.

Experience: With few experiences using the system, the drivers had no opinion as to whether it took a lot of effort to use the system while driving. Once experiencing it in snow conditions, they initially seemed to disagree that it took a lot of effort and that the benefits of the DAS outweighed the distraction of using the system. However, after more time using the system in snow, it appears that the distraction of the DAS began to outweigh the benefit, and most drivers agreed that using the system while driving took a lot of effort or had 'no opinion.' This result due to experience was significant, $\underline{F}_{CS}$ (5) = 6.13, $\underline{p}$ = .047.

Geographic: The rural drivers reported more disagreement (6 / 9 responses) than the metro and near-rural area drivers (1 / 11 responses) that using the system while driving took a lot of effort. On average, rural drivers disagreed that the system took a lot of effort to use while the near-rural drivers agreed that the system took some effort to use.

Overall: The average for Interview 3 shows that by season's end drivers began to think that it took some effort to use the system while driving, though the average was close to 'no opinion.' Only two (rural) drivers reported that using the system did not take a lot of effort, the rest (five) agreed that using the system took a lot of effort to use while driving (two of these had 'no opinion'). This shows that system-experienced drivers, regardless of geographic area and benefit, eventually realized that using the system took an amount of effort that they might not be willing to give.

Drivers were asked to indicate the level of (dis)agreement with the statement "The DAS was useful in good visibility" as a measure of perceived acceptance of the system.

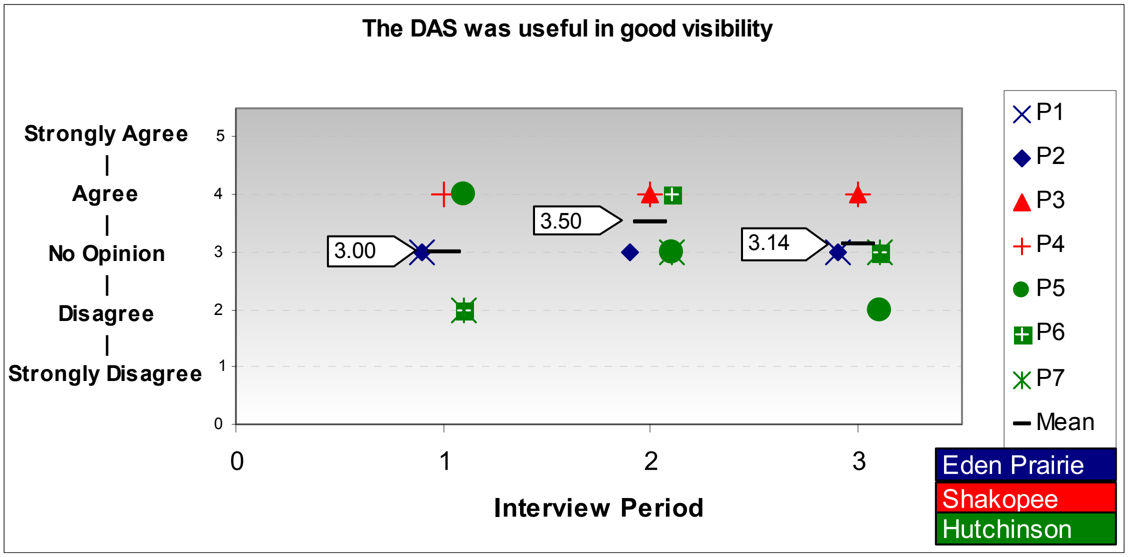


Figure 4.15. Interview data for statement "The DAS was useful in good visibility."

Experience: It seems that drivers had no opinion about the usefulness of the system in good visibility. This may be due to the fact that they probably did not use the system in good visibility conditions. Also snow did not drastically affect their opinions of the system's usefulness in good visibility. As of Interview 2 most drivers agreed that the system was useful, however these scores receded back to 'no opinion' by the Interview 3, though these trends based on experience were not significant.

Geographic: It seems that the drivers closer to the metro area (metro, near-rural) were more likely to agree that the system was useful in good visibility than rural drivers. Near-rural drivers consistently rated the system as being useful in good visibility. The rural drivers more often than not disagreed that it would be useful in good visibility or had 'no opinion.'

Overall: Overall most drivers had 'no opinion' on whether the system was useful in good visibility. This may have been a product of training, where the drivers were told that the system was intended to be used in poor visibility conditions. The other opinions of the final interview were definitely divided by geography, where both near-rural drivers found it useful, yet the rest of the drivers had 'no opinion' or disagreed as to its usefulness.

Drivers were asked to indicate the level of (dis)agreement to the statement "The DAS was useful in poor visibility" as a measure of perceived acceptance of the system.

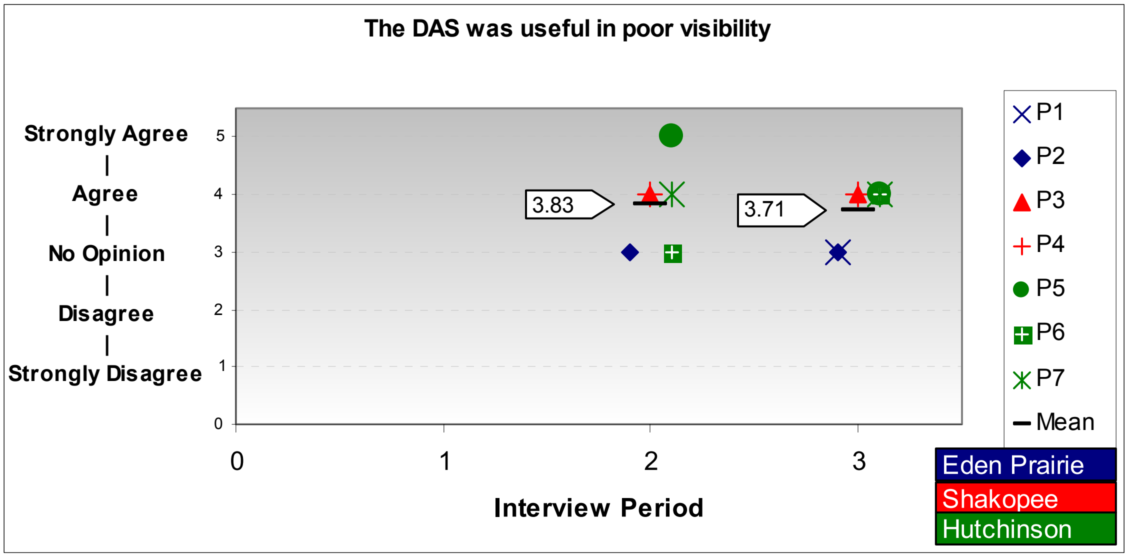


Figure 4.16. Interview data for statement "The DAS was useful in poor visibility."

There is no data for Interview Period 1 on this question. This is because there were no snow events before Interview 1, so the question was not asked.

Experience: The drivers agreed that the system was useful in poor visibility. This effect was more consistent (yet not as strong on average) during Interview 3, after having more experience driving in snow conditions. This may have been a product of training, where the drivers were told that the system was intended to be used in poor visibility conditions. However, these trends based on experience were not significant.

Geographic: There seems to be no clear geographic trend, though overall rural and near-rural drivers agreed that the system was more useful than metro drivers did. This is evident in that nine out of ten rural and near-rural ratings agreed that the system was useful in poor visibility. Again, this may be a product of having learned during training that the system's intent is to be used in poor visibility conditions.

Overall: It is apparent that by the third interview, five out of seven drivers (all rural and near-rural) found the system to be useful in poor visibility, and the other two had 'no opinion.' Through training and usage of the system in snow conditions, drivers believe the system to be useful in the conditions it was intended to be used. This may have been a product of training, where the drivers were told that the system was intended to be used in poor-visibility conditions.

Drivers were asked to indicate the level of (dis)agreement with the statement "Using the DAS improved my plowing performance" as a measure of perceived acceptance of the system.

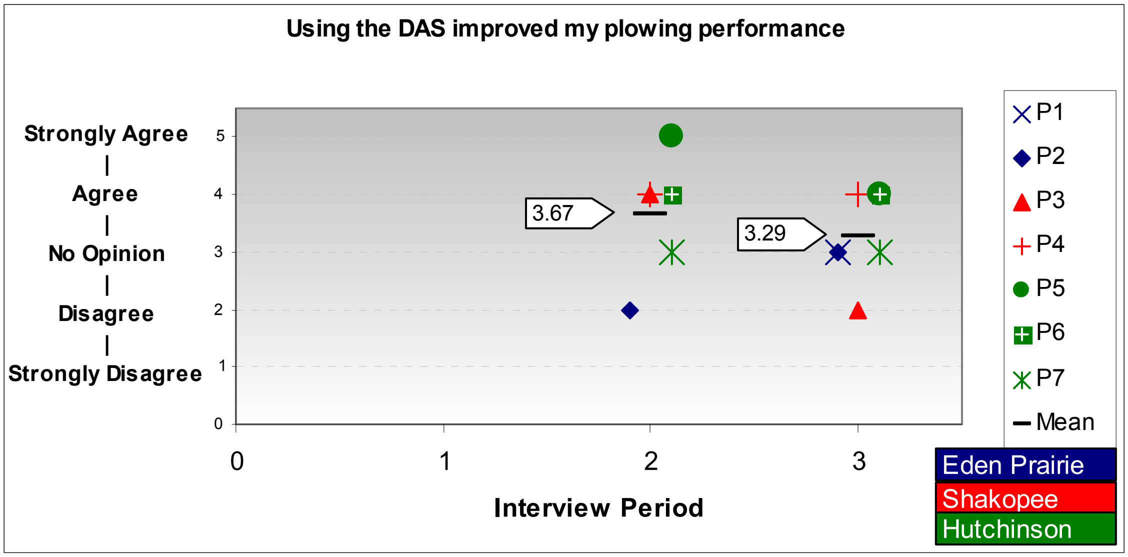


Figure 4.17. Interview data for statement "Using the DAS improved my plowing performance."

There is no data for Interview Period 1 on this question. This is because there were no snow events before Interview 1, so the question was not asked.

Experience: After their first experience with snow events, the drivers tended to agree more that the DAS improved their plowing performance, but in Interview 3 they seemed to have 'no opinion' overall on the matter. It seems that the more experience drivers had using the system, the more they disagreed or had 'no opinion' of whether it helped them plow or not. However, these trends based on experience were not significant.

Geographic: Overall rural drivers seemed to agree that the system improved plowing performance while near-rural and metro drivers were less enthusiastic. Differing weather conditions due to geographic area may have played a part in these disparaging agreement ratings.

Overall: By the third interview, the drivers are mostly split between 'no opinion' (three drivers) and agreeing that the DAS improved their plowing performance (three drivers). Overall, the average for the rural drivers was more in agreement with the DAS improving plowing performance, while the metro and near-rural averaged at 'no opinion.' This suggests that drivers had not used the system while plowing, and so did not have an opinion on how it might improve their performance. Alternatively, drivers who did plow while using the system were not as likely to say they benefited from using it. Geography, and thus road conditions, also seem to be an important factor in believing the system helped improve their plowing performance.

Drivers were asked to indicate the level of (dis)agreement with the statement, "The DAS provided useful information in addition to my traditional visual cues" as a measure of perceived acceptance of the system.

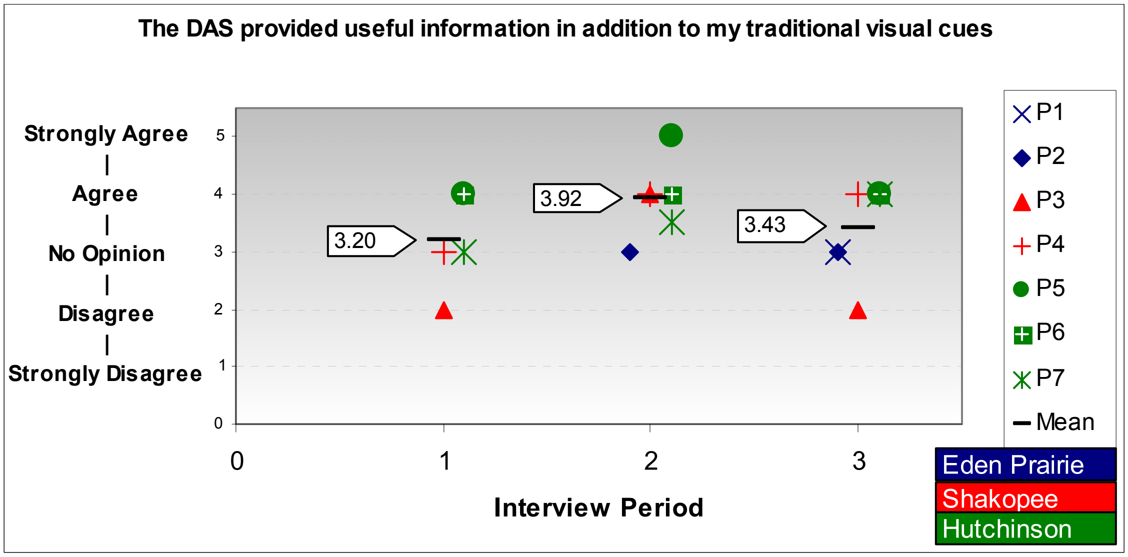


Figure 4.18. Interview data for statement "The DAS provided useful information in addition to my traditional visual cues."

Experience: Before experiencing the system that much, the drivers had 'no opinion' or slightly agreed the system provided useful information in addition to their traditional visual cues. After experiencing snowy weather, however, they agreed that the system provided useful information. Even though their reliance rating tended to drop by the third interview period, a majority of drivers seemed to still feel that the system provided useful information. This trend was almost supported statistically, as the results approached significance, F_{CS} (5) = 4.77, p = .092. By this last interview, drivers may have learned what information the HUD could truly provide versus what they thought it might and what it does not provide.

Geographic: Throughout the interview periods, the rural drivers reported a higher agreement in the system providing useful information than the metro and near-rural drivers. On average, rural drivers agreed that they believed the system provided useful information in addition to their traditional visual cues. Near-rural drivers we not as sure, agreeing only three out of six times over all of their responses. It seems that more rural drivers found the HUD to provide useful information, suggesting that the usefulness or nature of the information provided is geographically dependent and more useful in rural areas.

Overall: By Interview 3, three of the seven drivers disagreed that the DAS provided useful information in addition to traditional visual cues. Also, four out of five rural area drivers reported the HUD information was useful. This shows that after having time to see what the system offers, especially in snow conditions, the drivers agreed the information on the HUD was useful.

Drivers were asked to indicate the level of (dis)agreement with the statement "It was easier for me to drive while using the DAS" as a measure of perceived acceptance of the system.

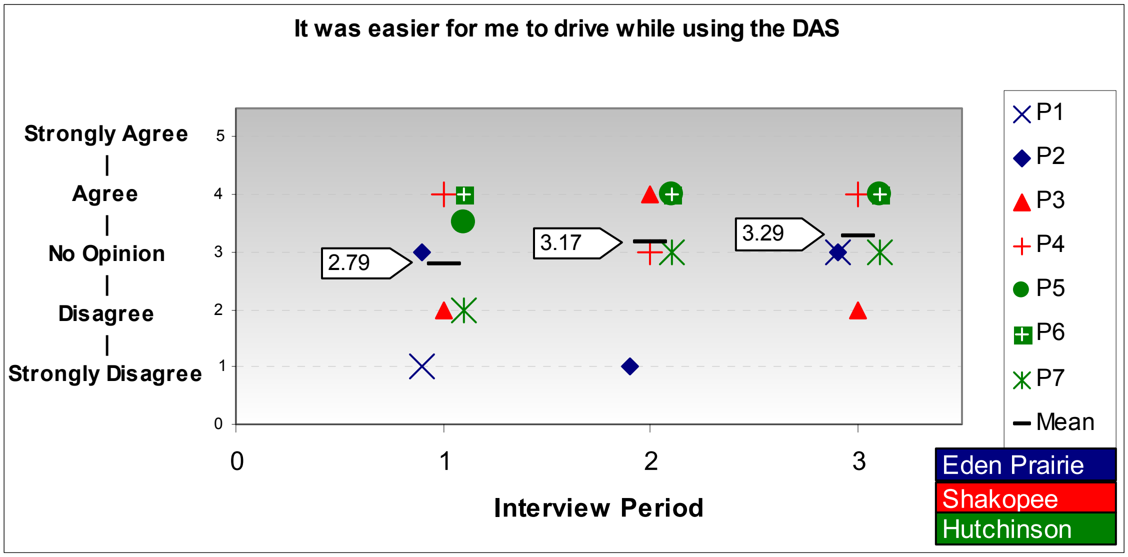


Figure 4.19. Interview data for statement "It was easier for me to drive while using the DAS."

Experience: With experience came a somewhat stronger agreement as to whether it was easier to drive while using the DAS. The drivers consistently had 'no opinion' if it was easier to drive with the system. More drivers agreed that it was easier to drive while using the system after seeing how the system could help them in snow events. Even so, they did not waver much from having 'no opinion.'

Geographic: The rural areas reported slightly more agreement with it being easier to drive while using the DAS (6 / 9 responses) than the metro areas did (3 / 11 responses). On average, rural drivers agreed that it was easier while using the system, and near-rural drivers never had that strong of an agreement. This may suggest that it was easier for the rural drivers to integrate the system into their plowing and driving routines.

Overall: The average for Interview 3 shows that the drivers did not have an opinion as to whether it was easier to drive with the DAS or not by the season's end. Only one driver (near-rural) reported that it was more difficult to drive while using the system. Because there is not a strong geographic trend, this shows that all of the drivers were not sure if it was easier to drive while using the system.

Drivers were asked to indicate the level of (dis)agreement with the statement "I was satisfied with the overall performance of the DAS" as a measure of perceived acceptance of the system.

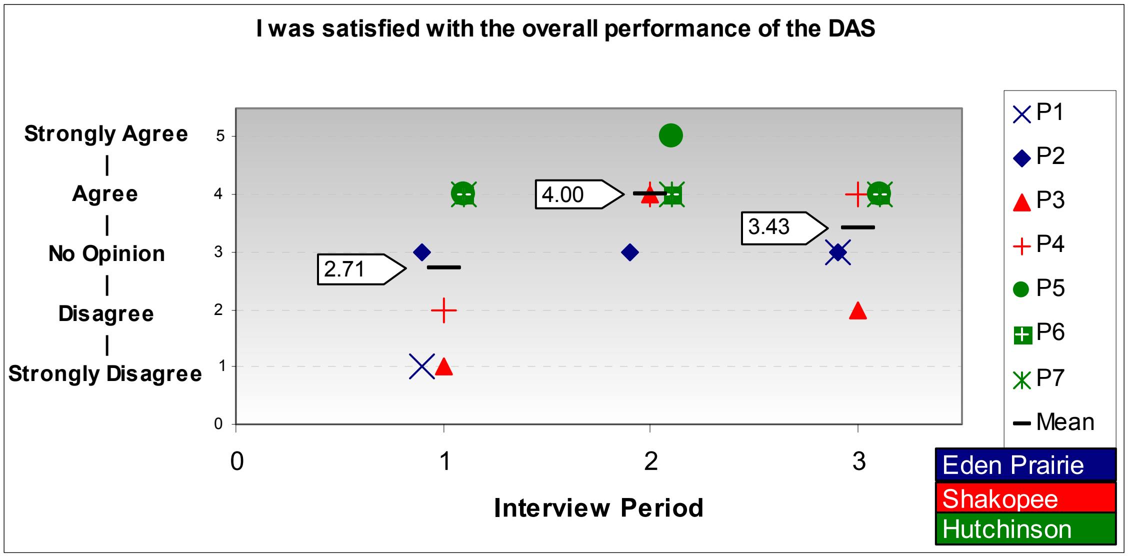


Figure 4.20. Interview data for statement "I was satisfied with the overall performance of the DAS."

Experience: Before experiencing the system that much, the drivers tended to have 'no opinion' or slightly disagreed that they were satisfied with the overall performance of the system. After experiencing snowy weather, however, five out of six agreed that they were satisfied with the performance of the DAS, the other stating 'no opinion.' Even though their satisfaction rating dropped by the third interview period, a majority of drivers still seemed satisfied with the performance of the system. This trend was almost supported statistically, as the results approached significance, $\underline{F}_{CS}$ (5) = 5.00, $\underline{p}$ = .082. It is possible that drivers experienced more disruptions in GPS functionality and other flaws inherent in the system during their prolonged exposure that they were not aware of initially.

Geographic: Throughout the interview periods, the rural drivers reported consistent agreement in being satisfied with the system's performance while only three out of eleven metro and near-rural driver responses did.

Overall: By Interview 3, four out of five rural and near-rural area drivers reported they could rely on the DAS for guidance. This shows that after having time to see what the system offers, especially in snow conditions, the drivers were somewhat satisfied with the system. Three out of seven drivers disagreed that they were satisfied with the overall performance of the DAS. Overall drivers were looking for some changes to be made in the functioning and elements of the system before they could feel completely satisfied with it.

Acceptance – Usability Summary
Overall, the drivers slightly agreed that the system was user-friendly, but all found parts they enjoyed using and other aspects that were perceived as requiring improvement. By the end of the season, most drivers were slightly positive about the system's usability, though the mean reflects 'no opinion.' This is most probably due to the various geographic effects present in this grouping. It seems that different geographic regions found the system useful in different situations, though rural drivers agreed with its usefulness more often.

Reliability
Drivers were asked to indicate their level of (dis)agreement with the statement "The DAS provided me with reliable information" as a measure of perceived system reliability.

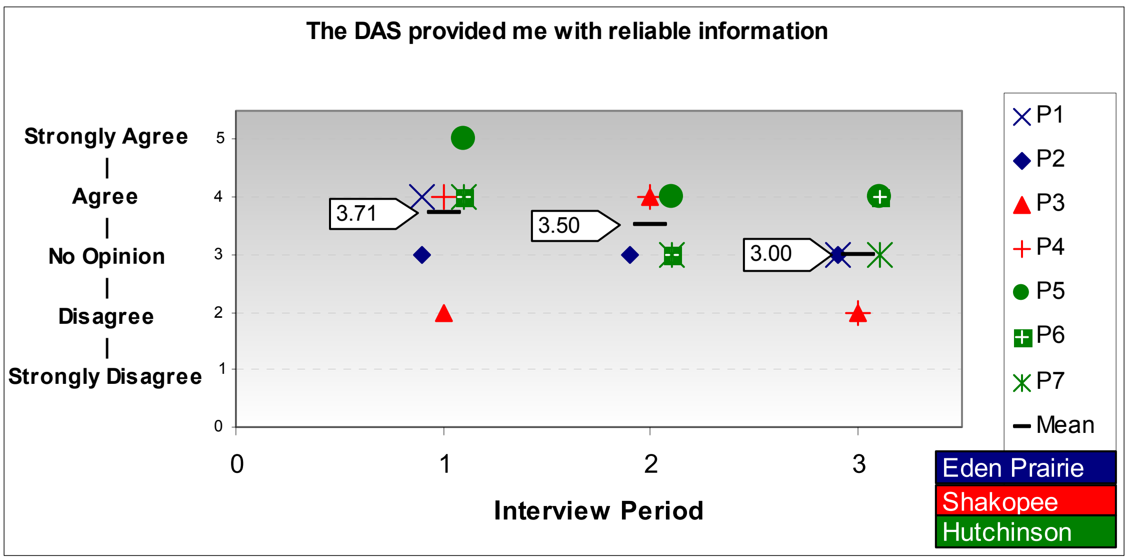


Figure 4.21. Interview data for statement "The DAS provided me with reliable information."

Experience: As shown by the group means for each interview period indicated by the arrow icon, initially drivers agreed that the system was providing them with reliable information. This opinion seemed to remain after using the system in snow (Interview 2) but then tended to drop to 'no opinion' after more prolonged usage in snow conditions (Interview 3), though this trend was not significant. It is possible that drivers experienced more disruptions in GPS functionality and other flaws inherent to the system during their prolonged exposure that they were not aware of initially.

Geographic: There is no clear trend by geographic area. Rural drivers seemed to find the system to be the most reliable over all the interviews (6 / 9 responses). Four out of eleven near-rural and urban driver responses disagreed that the DAS provided them with useful information.

Overall: Though opinions differed by geographic area, most drivers (5 / 7) were unsure as to whether the system provided reliable information by Interview 3. Near-rural drivers disagreed that it gave reliable information, while two out of three rural drivers agreed that it gave reliable information. Geography or the particular truck driven may have played a role in how reliable the system's information was, especially after having firsthand experience of the benefits and inconsistencies inherent to the system. The downward trend also suggests that the initial motivation and training may have been a large factor in the perceived reliability of the system.

Drivers were asked to indicate their level of (dis)agreement with the statement, "I trusted the DAS to provide me with accurate information" as a measure of perceived system reliability.

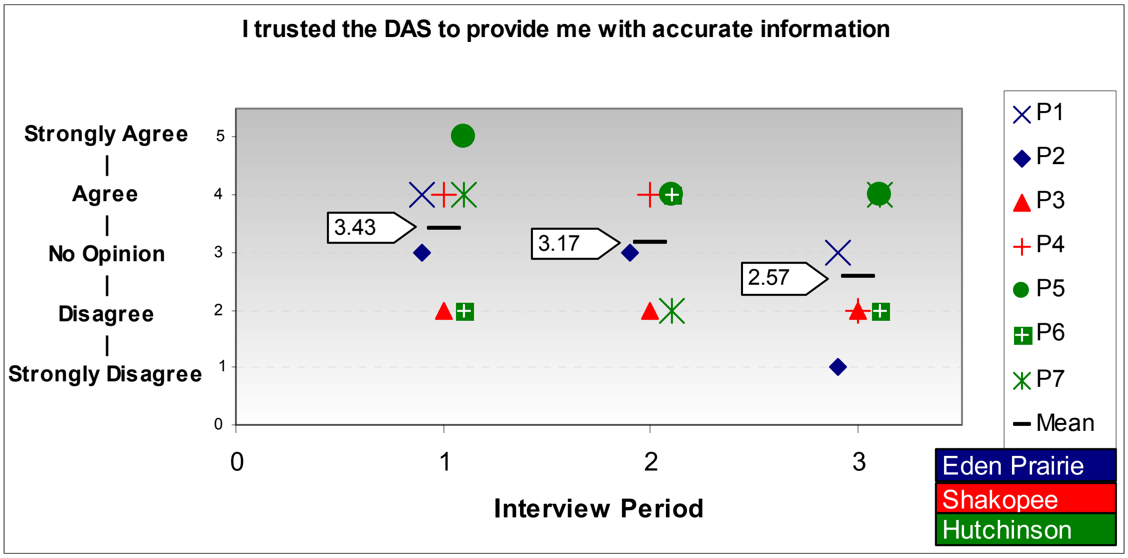


Figure 4.22. Interview data for statement "I trusted the DAS to provide me with accurate information."

Experience: Initially it seemed that drivers somewhat agreed that the system was providing them with trustworthy information. After using the system in snow, drivers seemed to have 'no opinion' and then they somewhat disagreed that it provided accurate information after more prolonged usage in snow conditions, though this trend was not significant. It is possible that drivers experienced more disruptions in GPS functionality and other flaws inherent in the system during their prolonged exposure that they were not aware of initially.

Geographic: The drivers in the rural and near-rural areas were slightly more likely to think the system provided accurate information than the metro drivers. Rural and near-rural drivers were consistently split, some agreeing that the system was reliable and others saying that it was not. By the final interview, the near-rural drivers felt that the system did not provide them with accurate information.

Overall: Though somewhat divided by geography and close to 'no opinion,' drivers tended to think that the system was not providing them with as accurate information as they would have liked. Near-rural drivers thought it gave inaccurate information, yet only one out of three rural drivers thought that it gave inaccurate information, the other two thinking it gave accurate information. These results suggest that something is missing in the drivers' belief that they are receiving accurate information. The downward trend also suggests that the initial motivation and training may have been a large factor in the perceived accuracy of the system.

Reliability Summary
It seems that with more experience using the DAS, drivers rated the system as less reliable. Also, rural drivers rated the system as more reliable than near-rural and metro drivers. Since the system was maintained throughout the study, and the snow did not seem to influence these opinions, there was something inherent to the system experience that caused drivers to not like the system. Quite possibly, more experience with losing the GPS fix (signal) may have been the cause of this problem. Also, the geographic location of the driver's route, and thus the visibility conditions they experienced, played a role in their opinions of reliability.

Open-Ended Questions and Statements

If there was a follow-up question to one of the preceding scaled questions, subjective comments were summarized for all of the interview periods.

Operability

Drivers were asked, "What have you learned from using the DAS that you should have been told before using it?" as a measure of perceived system operability. When drivers had anything to say about remembering how to use the system, most of it was positive. Two remarked that a good job was done during training and during the subsequent ride-along. Another two remarked it was easy to use while another person claimed to learn from experience how to best set it up. "The hardest part is lining up the display with the actual lines once I am on the road and then keeping it lined up," was the sentiment of a few drivers throughout the season.

Safety

Drivers were asked, "In what ways did using the DAS make you a safer driver?" as a measure of perceived system safety. Most drivers thought the DAS helped them stay in their lane and show them where the lane was. Some found the radar helpful in seeing traffic and stalled cars. Others thought that the seat let them know they were still in the lane, especially when concentrating on other things. One driver was animate on keeping the system in his truck because he claimed it helped him avoid a head-on collision.

A few drivers felt more stress in worrying whether the system was working properly than if they were not using the DAS. Two drivers thought that the changing color of the radar (and road lines) in the HUD was hard to get used to and didn't understand the meaning of the colors or how they translated to real-world distances or speeds. Some found setting up the HUD and keeping it aligned while driving to be troublesome.

Drivers were also asked, "Why did you find it easier/more difficult to drive while using the DAS?" as a measure of perceived system operability. Many drivers thought that the seat made them feel safer by allowing them to feel and "know exactly where the edges of the lanes where." This was important when their attention was diverted by other business during low-visibility conditions. The radar was also cited as useful.

The HUD combiner was cited as a problem because it was thought to reduce the distance at which some drivers could see things. Setting up and adjusting the combiner was difficult while driving. It was also difficult to see through the HUD when oncoming cars produced glare in the combiner. An overall opinion was that the system was too much to pay attention to with everything else they have to do while concentrating on driving and plowing.

Acceptance

Acceptance – Trust

Drivers were asked, "If you had trouble trusting the DAS, what were your reasons for this?" as a measure of perceived system acceptance. There was one comment that there is too much going on in the HUD between the road lines and the radar targets. Drivers are used to not having any information, so they are uncomfortable when they suddenly receive a lot of information from the DAS. Also, drivers may have not retained complete knowledge of the system from training, as exemplified when one driver remarked of having trouble plowing shoulders before he learned how to adjust the center point of the road from the Settings panel.

Drivers were also asked, "Would you like to have the DAS permanently installed in your truck?" ('Yes' or 'No'). This was asked to get the drivers' opinions of overall acceptance and satisfaction in the system.

Interview 2	Yes	No
Eden Prairie	0	1
Shakopee	1	1
Hutchinson	3	0
Total	4	2

Interview 3	Yes	No
Eden Prairie	0	2
Shakopee	1	1
Hutchinson	3	0
Total	4	3

Table 4.5. Interview data for statement "Would you like to have the DAS permanently installed in your truck?" (yes/no)

There is no data for Interview Period 1 on this question. This is because this question was conceived as a clarification of Question 19 after Interview 1. As can be seen in Table 4.5, whether or not drivers wanted the system installed in their truck was a factor of where their station was located geographically. All rural and near-rural drivers except one would like to have the DAS permanently installed in their truck.

Drivers' opinions did not change with further experience with the system in snow conditions. The same drivers who said they would like the system installed in Interview Period 2 also wanted it installed in Interview Period 3.

Most of the drivers did not recommend installing the system in all trucks, instead suggesting that the system be installed in one vehicle per station. In this way, the DAS could be used in emergencies to help clear the way for ambulances, fire trucks, etc. who may need to be out during extreme weather. When people wanted the system installed in their vehicle, their reasoning was that it helped them stay in their lane.

When drivers did not want the current system installed in their truck, the reasoning was that the system has too many 'problems' right now. They said they would change their mind if the reliability of the system was greater, possibly through more testing and experience with the DAS on the road. Overall, there seems to be a problem with comfort and trust in the system; drivers didn't put their faith in the system to work consistently. The system was also noted as being too big and clumsy, or only useful for more rural areas.

Acceptance – Usability
Drivers were asked, “In what ways did using the DAS improve your plowing performance?" as a measure of perceived system acceptance. Many drivers liked using the seat as their main information source, mainly because they could feel the lane when concentrating on other things. Just as many drivers like being able to see the center line and see where the lane is. Drivers also like being able to see where ambient traffic was, since that was stated as their biggest concern. One driver even said that he would rather end up in the ditch than hit another car.

Reliability
Drivers were asked, “What was most useful to you/what would be your ideal configuration of the DAS?” as a measure of perceived reliability of the system. More than half of the drivers preferred just using the seat to guide them, the most cited reason for this being that you could look away from the road and still feel if you are going out of the lane. This agrees with the recommendations of previous research on similar guidance systems (McGehee and Raby, 2002). Since drivers have other tasks and functions to pay attention to, this is useful to learn. Almost half preferred seeing the lanes in the HUD, or a combination of the HUD and the seat. The radar was also cited as a useful tool during low visibility.

Drivers were also asked, “What parts of the current DAS *should be removed*?” as a measure of perceived reliability of the system. If drivers had anything to complain about, it was that the system disrupted their radio, either turning off the FM radio or interfering with radio communications. Also, drivers had a problem with the bulky appearance and feeling of the HUD. A few drivers thought the radar images were too much, thinking that the lines on the road were enough for guidance and everything else just became a distraction. The large box containing the system was also mentioned.

Drivers were also asked, “What things *would you like added* to improve the DAS?” as a measure of perceived reliability of the system. By far, the most suggestions given for improvement involved the HUD. Foremost, drivers wanted a way to easily and more quickly adjust the combiner. Also many drivers thought the current implementation was too large or in the way. As for functioning, it was suggested the radar pick up oncoming vehicles, more so in cases where the car is coming straight at the driver, such as in low visibility or when plowing a center turn lane. It was also stated that the tint of the combiner limited the distance that drivers could see at night.

Drivers liked using the system, but most made the caveat that they like it only when the GPS was 'working' (ie. when they got constant satellite fix). However, since a constant fix can never be assured, this presents a problem with overall perception of system reliability. The most common problem reported was a problem with getting a GPS fix of suitable solution quality and keeping this signal. One driver said that he uses the system until he looses the solution, and then he just shuts the whole system off. Returning to using natural reference points after using the system also seems to be difficult. Obviously, drivers are having a tough time trusting the system and GPS is at least partly to blame.

Comments on Specific Components

Listed below are any other comments that drivers may have made during the interview session. These responses are organized by the component of the DAS that they pertain to.

HUD

Drivers liked being able to see the lines of the road, and (apparently) oncoming cars. They wanted the seat and HUD to work, which makes sense since one assists with seeing the lane and the other helps with lateral assistance. Other things they would like to see included radar of oncoming traffic, speedometer or other gauges displayed on the HUD so as not to have to look down, and rear radar.

However, there were numerous complaints about the position and quality of the combiner over the course of the experiment. In early February, the combiner in the McLeod County truck fell off its supports. It was reported that stress and vibration on the frame weakened its connection to the truck. In mid-march, this same combiner screen swung down while driving, hitting the driver on the face. Realizing that such performance is unacceptable, the combiner has been redesigned and is currently being tested in several other field operational tests.

By far, the biggest complaint of the HUD (the combiner specifically) was that it was very difficult to line up and keep aligned. A serious issue that came up regarding the radar was that targets of unmapped signs would come up so frequently that some drivers admitted to not paying attention to any target, which indicates that real targets were ignored as well. Other HUD issues included: displaying too much information, changing the brightness was too difficult to accomplish while driving, the changing colors of the radar and lines being hard to get used to and relate to the real world, and the combiner mounted too close to the drivers heads.

Haptic Seat

Most drivers liked using the seat, many enjoyed using it alone and some using it while also using the HUD. Some of these drivers said they liked the seat because it was the most noticeable signal that did not annoy them, such as when the radio cut out during audio warnings.

Audio Warnings

No one had anything positive to say about the audio warnings. Most drivers complained how it turned off their radio (FM or communication). The most common complaint was that they did not want to change the settings every time they plow a shoulder, so they just turned off the audio before leaving the station when they knew they were going to plow shoulders.

FOT Interview Summary

As stated above, it is hard to put much weight behind the conclusions from the FOT interviews. Nevertheless, this summary of the findings from the interviews expresses the overall idea of how the drivers felt about their limited experience with the DAS in low-visibility conditions (i.e. ideal usage conditions).

The geographic location of the driver's route, and thus the visibility conditions they experienced, played a large role in their opinions of the DAS. Drivers in more rural areas who perhaps had more opportunity to using the system in its intended conditions tended to like what they saw. On the other hand, drivers in urban settings were for the most part unwilling to use the system.

This willingness to use the system, even if not in low-visibility, became a polarizing factor when drivers were asked to rate their acceptance of the DAS. As is to be expected, drivers who are used to how a system functions tend to be more trusting of it, if only because they know when to expect system problems. This is compounded by the fact that the DAS presents much more information than what they are usually exposed to.

Also, drivers who use the DAS form more informed opinions on what components they like or dislike. For drivers who reported using the system in the worst conditions, the HUD was useful when it didn't vibrate out of alignment and the haptic (seat) lateral warnings were quite useful when they had to take their focus off of the road. Drivers did realize that this was not the final implementation of the DAS and reported not wanting it installed in all trucks. Overall they see it as being useful to install in a few trucks for emergency purposes.

Since the DAS presents additional information to the drivers, they found it somewhat distracting and need to get used to processing this additional information in the driving context. While learning to do this, drivers reported feeling safer and having more control while driving. These opinions suggest that even though drivers have additional processing demands, they believe that they are benefiting from it.

In regards to some comments drivers made about the DAS providing unnecessary or unneeded information, it can also be argued that even poor navigational information provides some situation awareness support that they were not receiving before. Also, people have a tendency to adapt to the situations and interfaces given to them, often using what features they find useful and not even trying to learn the others that seem too hard to learn or use (Sanders & McCormic, 1993). In such a way, the DAS may provide longtime users with additional SA cues that were not apparent with our drivers who had limited experience with the system in low-visibility conditions.

A few drivers expressed that they felt additional stress due to not trusting that the system would work properly, finding the instability of the combiner as annoying, or from not understanding elements of the HUD. Issues such as these and the proposed improvements to the DAS components have concrete solutions that should be resolved so that no additional strain is placed on drivers.

FINAL SURVEY

The final survey was intended to be given after the FOT, just as it had been in the previous year's study. However, it was decided that drivers would have a better opinion of the system after using it during the track testing. The Final Survey was given after all track testing conditions were driven and all interviews were conducted (Rakauskas et al., 2003).

Results from the final survey are presented in the tables below. For most questions, the overall mean is presented for the scaled responses, along with the standard deviation (s.d.), minimum and maximum ratings. When discussing results, the mean ratings were broken into high (i.e. scores from 100 to 67), moderate (i.e. scores from 66 to 34), and low (i.e. scores from 33 to 0) categories for simplicity.

For some questions, a "yes" or "no" response was required and the percentage of "yes" responses is presented. Some of questions invited comments or further open-ended responses. These responses are presented below the appropriate questions, followed by the percentage and number of participants who responded similarly.

When available, the results from last year's final survey are presented alongside this year's results. This data represents the responses from nine (n = 9) drivers this season, and seven (n = 7) drivers last season. The means for each sample of drivers were compared and tested for statistical significance using t-tests (for scaled questions) or chi squares (for yes/no questions). If the test value was significant, the result is noted in a footnote. A significant finding implies that the opinions of drivers in 2003 were not the same as in 2002.

However, it may not be a fair assessment to compare the results from 2002 and 2003 for several reasons. First, last year's data was collected from drivers who were not able to use the system in the conditions it was intended in the field. Though drivers in this year's study also did not use the system in these natural conditions, they did use it in simulated low visibility during the track testing. For this reason, the 2003 data is different from the 2002 data in that last year's drivers did not experience the system in the track setting. Second, the sample of drivers used for the survey results last year was comprised of both snowplow and ambulance drivers. This year only snowplow drivers were involved in the study. Also, improvements were made to the reliability and stability of the system since the 2002 season. Therefore, results showing improvements may be due to technological advances instead of changes in driver attitudes.

Safety

Drivers' opinions on the stress and fatigue associated with using the DAS are presented in Table 4.6.

Question	Results from winter ending in:			
		2003	2002	
How stressful was it to use the DAS?	**Mean:**	**65**	27	*
0 = Very Stressful	S.D.	31	17	
100 = Not at all Stressful	Min - Max	14 - 96	0 - 50	
Did you feel that you needed breaks more often than usual when using the DAS?	**Yes:**	**33%**	0%	'
Were you more fatigued than usual after using the DAS?	**Yes:**	**22%**	57%	

** Means are significantly different at .05 level ($t = 3.12$, $p = .008$)

' Means are marginally different at .10 level ($CS_{Pearson} = 2.87$, $p = .090$)

Table 4.6. Drivers' survey responses on their stress and fatigue associated with the DAS.

Even though drivers in this year's study thought the DAS was moderately stressful to use, they found the DAS to be significantly less stressful to use than the 2002 drivers. Consistent with this finding, only 22% (2 / 9) of the drivers reported that they were more fatigued than usual after using the DAS. However, a third (3 / 9) of the drivers reported that they needed breaks more often than usual when using the DAS, which was a marginally significant increase from 2002 when no drivers reported needing more breaks.

Acceptance

Acceptance – Trust

Drivers' opinions of their confidence in the DAS are reported in Table 4.7.

Question	Results from winter ending in:		
	2003		2002
How much did you trust the DAS?	Mean:	**52**	
0 = Not Trust at all	S.D.	27	
100 = Trusted Very Much	Min - Max	14 - 94	
How much did you rely on the DAS?	Mean:	**62**	
0 = Did Not Rely on it	S.D.:	24	
100 = Relied on it Very Much	Min - Max	26 - 94	
How much confidence did you have in the DAS?	Mean:	**58**	
0 = No Confidence	S.D.:	28	
100 = Complete Confidence	Min - Max	16 - 98	

Table 4.7. Drivers' survey responses on their confidence in the DAS.

Drivers reported having moderate trust and confidence in the DAS. They also reported relying on the DAS a moderate amount. However, it should be noted that there was a large range of ratings for all three of these questions, indicating a wide range of opinions between individual drivers. These results are similar to those reported earlier from the Trust questionnaire given after the DAS and TRAN conditions. Since the confidence questions were added during this testing year, comparisons could not be made between the two winters.

Acceptance – Usability

Drivers' opinions of the usefulness of the DAS are reported in Table 4.8.

Question	Results from winter ending in:			
	2003		2002	
In general, how useful was the DAS?	**Mean:**	**67**	59	
0 = Not at all Useful	S.D.	21	26	
100 = Very Useful	Min - Max	31 - 96	22 - 90	
How useful were the lane markings on the head-up display?	**Mean:**	**70**	65	
0 = Not at all Useful	S.D.:	21	20	
100 = Very Useful	Min - Max	43 - 95	37 - 95	
How useful was it to see objects ahead of you on the head-up display?	**Mean:**	**58**	57	
0 = Not at all Useful	S.D.:	29	32	
100 = Very Useful	Min - Max	15 - 87	21 - 96	
How useful were lane departure warnings?	**Mean:**	**75**	36	*
0 = Not at all Useful	S.D.:	23	25	
100 = Very Useful	Min - Max	18 - 95	0 - 73	

** Means are significantly different at .05 level (*t* = 3.21, *p* =.008)

Table 4.8. Drivers' survey responses on the usefulness of the DAS.

Drivers seemed to find the DAS very useful, especially when considering the lane-assistive lane markings on the head-up display. The positive usefulness ratings coincide with the 2002 testing results. Drivers also thought seeing objects ahead of them on the HUD was moderately useful, which was also the finding last winter.

This year's drivers felt strongly that the lane departure warnings were very useful. They also were significantly more adamant that the warnings were useful than last year's drivers. Nothing about the warnings themselves changed since last year; the only real difference between the systems was overall GPS and system reliability. This suggests that the warnings were more relevant in the operational context (i.e. low visibility) that the 2003 drivers experienced during the track testing, whereas the 2002 drivers had little experience with using the DAS in low-visibility conditions.

To explore this issue further, drivers' opinions of the lane departure warning system are reported in Table 4.9.

Question	Results from winter ending in:		
	2003		2002
How much did you like the center and end-lines changing color to red (on the HUD) as a lane departure warning?	**Mean:**	**79**	56 '
0 = Dislike Very Much	S.D.	13	31
100 = Like Very Much	Min - Max	62 - 97	9 - 94
How much did you like the rumble strip sounds as a lane departure warning?	**Mean:**	**40**	27
0 = Dislike Very Much	S.D.:	27	29
100 = Like Very Much	Min - Max	6 - 73	0 - 74
How much did you like the vibration at the edge of the seat as a lane departure warning?	**Mean:**	**72**	62
0 = Dislike Very Much	S.D.:	23	36
100 = Like Very Much	Min - Max	14 - 97	13 - 100
The lane departure warning system is a combination of the read road lines (on the HUD), the rumble strip sound, and the vibrating seat. Would you prefer another type of warning?	**Yes:**	**0%**	29%

' Means are marginally different at .10 level ($t = 1.84$, $p = .096$)

Table 4.9. Drivers' survey responses on the lane departure warning system of the DAS.

As far as lane departure warnings go, drivers reported liking the changing color of the HUD lines and the vibration of the seat. Drivers liked the HUD warning lines more this year than last, when drivers reported moderate liking of the warning. Though drivers reported moderately liking the audio system, their ratings tended to be more towards disliking the warning. When asked if there was another type of warning that they would prefer, all drivers responded "no." Last year, two (29%) of the drivers preferred another type of warning (though they did not comment on what these preferred warnings were).

Drivers' opinions on the ergonomics associated with using the head-up display (HUD) hardware of the DAS are presented in Table 4.10.

Question	Results from winter ending in:			
		2003	2002	
How comfortable were you with where the head-up display ("combiner") was placed?	**Mean:**	**55**	30	*
0 = Very Uncomfortable	S.D.:	24	16	
100 = Very Comfortable	Min - Max	8 - 77	2 - 43	
How comfortable were you with where the projector was placed?	**Mean:**	**67**	35	*
0 = Very Uncomfortable	S.D.:	25	24	
100 = Very Comfortable	Min - Max	14 - 95	4 - 66	

* Means are significantly different at .05 level (t = 2.49, p =.025; t = 2.60, p =.019)

Table 4.10. Drivers' survey responses on the ergonomics of the DAS head-up display hardware.

Drivers' were moderately comfortable with where the HUD combiner was placed, though drivers this year were significantly more comfortable with where it was placed than last year's drivers. This may be due to a number of drivers using the system both years and becoming more familiar and therefore more comfortable with it. Drivers this year were very comfortable with where the projector was placed and they also were significantly more comfortable with where it was placed than last year's drivers. This significant result is likely due to the fact that last year's participants included ambulance drivers who had problems with projector interfering in line of communication to the back of the vehicle.

Then drivers were asked to comment on these ergonomic comfort issues. Most of their comments involved the setup of the combiner. As seen in numerous places above, the drivers commented most on the stability of the combiner. Two drivers also did not like how the combiner was close to their faces, and another driver suggested the lane assistive information be projected onto the windshield as a solution to the same annoyance. One driver noted that it was difficult to have to set up the combiner each time he used it since he shared the truck (and therefore the system) with another driver.

Finally, questions were asked regarding how drivers would like a future/final version of the DAS. These responses can be found in Table 4.11.

Question	Results from winter ending in:		
	2003		2002
Would you like to have the final version of the DAS permanently installed in your vehicle?	**Yes:**	**56%**	57%
Would you use the final version of the DAS if it were permanently installed in your vehicle?	**Yes:**	**56%**	71%
Would you recommend the DAS to other drivers?	**Yes:**	**89%**	43% *
If it becomes technologically possible, would you like to see the oncoming traffic in the opposing lane on the head-up display?	**Yes:**	**67%**	71%

* Means are significantly different at .05 level ($CS_{Pearson}$ = 3.88, p =.049)

Table 4.11. Drivers' survey responses on the DAS final version.

Just over half (5 / 9) drivers said that they would like to have the final version of the DAS permanently installed in their vehicle, which is comparable to the number of drivers last year who wanted the final version. The same drivers who wanted the DAS installed reported that they would use it if it were installed in their vehicles. All but one of the drivers (8 / 9) reported that they would recommend the DAS to other drivers. This is a significant increase from 2002, suggesting that even if drivers were not more inclined to want or use the final version, they still had a more positive recommendation of it when describing it to other drivers.

Two-thirds (6 / 9) of the drivers thought it would be good to be able to see oncoming traffic on the HUD, which is comparable to last year's results.

Drivers were then given the opportunity to give any suggestions they have to improve the DAS. Again, two of the comments dealt with the actual physical components of the DAS and not content material presented ("Make the combiner easier to setup," and "streamline it, make it less bulky"). The other comment was to "get rid of extra warnings to eliminate sensory overload." This suggests that at least one driver felt that there were too many warnings being given to him/her from the DAS. Though no specific recommendations were provided, this is a pertinent comment to keep in mind for future assistive system versions.

Finally, drivers were given the chance to make any comments that they may have about their experience of driving with the DAS and Tape systems. Their responses are below:

- "The system saved me during a snow storm this winter – get all the bugs out and I'm sold."
- "It was very helpful in low visibility. I avoided an accident with the radar. A car came into my lane and I was able to move over to the shoulder in time to avoid hitting them because of the early warning (from the radar)."

- “I think the system would work well in very specific locations, such as consistent ‘whiteouts,’ low lighting, or low visibility of lane lines. Here in the metro, it really won’t be needed a great deal like it (would be) in outlying areas.”

Final Survey Summary

Overall, drivers found most aspects of the DAS useful, including the HUD and haptic seat lateral warnings as well as the lane assistive systems. Drivers also reported liking the lines that changed colors in the HUD, though it was reported before that some drivers did not know what this indicated or specifically how they were to apply this information to real world situations.

This year’s drivers had the advantage over the 2002 drivers of using the system in the low-visibility conditions it was intended for (during the track testing) as well as the potential for experience during the field operation testing. One finding relating to this difference was that the lateral warnings seemed to become more relevant in the operational context of low visibility.

Drivers reported moderate trust and confidence, as well as a moderate level of reliance on the DAS. Drivers also reported that the DAS was not stressful to use, an apparent improvement over results from 2002. However, a third of the drivers reported they would need breaks more often when using the DAS, when last year no drivers reported this. All told, drivers from last year did not have the proper experience with the system to make such judgments.

Drivers seemed to always be noting the instability of the combiner. Though they were more comfortable with where it was located than last year’s drivers, they felt it could be moved further from their heads and include features that made it easier to set up.

Almost all drivers said that they would recommend the system to other drivers, and area in need of improvement from 2002. This suggests that after becoming more familiar with its functions, a driver will have a much more positive attitude towards the DAS and will be willing to share that with others.

5 DISCUSSION

This discussion will cover the findings from both the FOT and track testing portions of this project. Full details of the test track experiment are presented in the supplemental track test evaluation document (Rakauskas et al., 2003).

The information from the FOT interviews presented some useful data on how drivers might use the DAS, and, more importantly, why they might not use the system during normal operations. This data allowed us to address whether the value of the system was apparent to operators.

It seems that drivers in more rural areas appreciate the functioning of the DAS more than urban drivers, and therefore also were able to explore the benefits and issues inherent with using such an assistive system while plowing. However, for the DAS to be seen as a useful and enjoyable system for all plow drivers, there are some improvements that need to be explored in both the structure and functioning of the system. Eliminating nonessential elements and features may hasten advancement towards this goal.

The track test experiment was intended to create a set of low-visibility conditions in which to test the DAS lateral warning and lane assistive technology. This allowed us to address all three of the research objectives stated above, which were:

1. Does the system support driver performance in a manner consistent with reduced crash risk?
2. Does the system support driver performance in a manner consistent with improved productivity?
3. Is the value of the system apparent to operators?

In regards to reducing crash risk and improving productivity, results from the driving performance measures gave us an indication of how the DAS supported driver performance. Using the DAS during low-visibility conditions helped drivers maintain their lane position as well as, if not better than, the clear visibility condition. In this way, drivers spent less time outside of the lane, and when they did leave the lane they were quicker to respond to the situation. The system also made drivers feel that they could not speed over the suggested limit, as was the case in low-visibility and more so the case in the clear visibility condition.

Drivers reported being more taxed while in the low-visibility condition, yet it was initially unforeseen in our predictions how much workload would be added by using the DAS. The additional mental effort bought the driver increased performance as evidenced by the speed performance variables, where the drivers were able to maintain similar average speeds for both the DAS assisted and low-visibility conditions.

Using the DAS while it was transitioning to the 3M system produced more variability in speed and steering position, thus suggesting that similar frequent losses of GPS fix would be detrimental to drivers' performance. Though this transitioning did prove to also add subjective mental workload as well as cause drivers to have more steering corrections, both of these results were also found during the normal stable DAS condition.

Using the DAS while it was transitioning to the 3M system produced more variability in speed and steering position, thus suggesting that similar frequent losses of GPS fix would be detrimental to drivers' performance. Though this transitioning did prove to also add subjective mental workload as well as cause drivers to have more steering corrections, both of these results were also found during the normal stable DAS condition. In addition, the implementation of the 3M system used in this study would, by design, lead to more variable driver behavior since it gives drivers information only about their immediate location in the lane, whereas the DAS provides a great deal of preview of what is to come.

This suggests that more effort is needed on the driver's part to maintain control of the vehicle while using the DAS. Even though drivers benefit from increased awareness of the driving environment by being able to maintain higher speeds and similar lane position accuracy; the mental effort they endure to perform at this level does not allow them the luxury of performing more additional tasks without being overburdened by common occurrences (e.g. in-vehicle tasks or hazard avoidance maneuvers).

The value of the DAS to the operators was again assessed through interviews and questionnaires. Though it seemed that each driver had his or her own opinion on what parts of the DAS were useful and satisfying, most tended to prefer the HUD for displaying lane assist information, or the haptic seat for lateral warning information.

It may be argued that, since the HUD is a very prominent feature of the DAS, technological-enthusiast drivers would therefore tend to rate it most positively because of its salience and presence. Also, it could be argued that, since the haptic seat does not interfere with the drivers' view of the road, the more cautious drivers would be drawn to this feature. In any event, it seemed that all the drivers reported they found benefit from some part of the DAS and that they trusted it.

A good number of drivers felt overwhelmed by the HUD at times. Even though the information was cited as useful, the combination of radar images coupled with the constant flow of road lines made some drivers anxious. This issue was compounded by the fact that the radar picked up seemingly false targets of road signs and mailboxes, which somewhat desensitized experienced drivers to real hazards. Even drivers who were receptive to the HUD could relate specific experiences during the FOT where there was too much information presented.

In addition to an overabundance of information, subjective comments indicated that some drivers were not able to translate the color differences in the HUD into real life distances. This may be a symptom indicating a lack of understanding for the driver population as a whole. Though the coding may be ambiguous to novice users, drivers were expected to learn this system during training. Therefore, the problem may be that the training received for this system indicator was not adequately remembered. Alternatively, the HUD may not be the best implementation for every driver. Therefore, training should emphasize the diversity of components available to them.

Other methods of portraying distance and movement in the HUD have been suggested (Ward 2001). These included having the road lines on the HUD appear to move towards the viewer at different rates relative to the vehicle's actual speed or varying the preview distance. It is recommended that the current depth cue/color system and other alternatives be tested further to better match real world expectations for visual cues.

Almost all drivers said that they would recommend the system to other drivers, which suggests that drivers were more familiar with the DAS' functions and thus they had a much more positive attitude towards the system. Drivers saw the DAS as useful, though they did not feel it was satisfying in its current form. It is clear that the system is continually improving and becoming more streamlined and robust, as seen in differences from last year's testing. Those that were not as favorable towards the system reported problems related to unfamiliarity and confusion with the HUD display or problems with the combiner.

Also, it seemed that drivers overall did not feel that the system helped to improve safety, but only helped them navigate. Though in low-visibility conditions this is in fact a way to improve safety, if drivers do not feel that using the system is going to help them feel safe they will most likely not use the DAS and instead rely on their own abilities. All efforts must be taken to make drivers comfortable with the system and help them realize the safety benefits that it brings to driving.

When using the tape backup system in the TRAN condition, drivers found it too sensitive and felt that this display needed to be refined in some way. As seen in other studies, there are other ways to implement such a lane detection system that may prove more effective (McGehee and Raby, 2002). Some examples of these include an indicator panel displaying lane position and warnings when a lane is traversed, lights on either side of the windshield to indicate when the vehicle is out of the lane, or haptic feedback through the steering wheel or seat. Some of these implementations agree with the majority of drivers who cited that it would be good to experience the backup system in the seat only.

In general, it seems that if drivers sense or think that the system will not have a stable GPS fix, they will not choose to use and trust the system both because of poor performance and due to the potential undesirability of the backup display. These opinions of the system will be a definite problem if not addressed through training or modification of transitions and the backup system.

Many of the trends presented in these analyses were consistent with our previous thoughts on how the DAS would perform. In some cases, the performance decrements could have been predicted and eliminated in the design phase through the application of human factors principles or simple user testing. It is strongly recommended that these human factors principles be applied in future iterations from the design stage forward, as opposed to using them only as a means of evaluation after implementation.

However, we should reiterate that all of our findings are based on a relatively small sample of eight drivers (or less in some instances). This may have resulted in fewer statistically significant findings resulting from the low power of our analyses. For the purposes of this evaluation we felt that the significant findings and trends were adequate to critique the operability, safety, and usability of the DAS in this context. Significant results and the strong trends found in the data should be confirmed for reliability through larger samples of drivers before they are taken as trends for all snowplow operators.

CONCLUSIONS

This project is a study to determine the usefulness of the Driver Assistive System (DAS) in context of plowing roads during low-visibility conditions. An experimental design in the context of a field operational test was originally used to compare driving performance, driver workload, and system performance in a naturalistic setting. It was found that geographical location of the driver's route played a large part in the desirability of the system. In this way, drivers in more rural areas preferred the system due to the lack of lighting and visual guidance while driving in low-visibility conditions.

However, it was decided that the field testing did not provide enough experience using the DAS during low-visibility conditions to make us confident in the drivers' experiences. For this reason, it was necessary to use an additional experimental design of a track test to compare driving performance, driver workload, and system performance under low-visibility conditions (the Objective and Subjective data from this track test are discussed in Rakauskas et al., 2003).

Performance while using the DAS was comparable to that of normal low-visibility conditions in terms of average speed and speed variability. The system also enabled drivers to maintain their lane position during low visibility as well as (and sometimes better than) during clear visibility conditions. However, drivers did exhibit more steering corrections and were less responsive to hazardous events while using the DAS and while transitioning to the 3M system. This indicates that it was more difficult for some drivers to maintain smooth and consistent control of the truck while using the DAS.

Subjectively, drivers liked the system and felt there were benefits to using it when the situation warranted. They were supportive to see future iterations of the DAS, especially if they would be less bulky and provide them with more stable view of the road. This includes not only increasing the stability and consistency of GPS signals but also the stability of the HUD component. Some drivers also felt that some of the components were overwhelming, leaving most with distaste towards the audio warnings. Overall, drivers would like to have the DAS available to them in emergencies and extreme conditions and liked being able to customize which components were on, depending on the situation and their preferences.

Many of the trends presented in these analyses were consistent with our previous thoughts on how the DAS would perform. However, do to the small number of drivers tested in the FOT and track testing studies, there was low power for our statistical analyses which resulted in a reduction in significant findings. Even so, the trends have been presented as tentative effects of the system, for which we encourage further research with the DAS on larger numbers of drivers.

Overall, it seems that the DAS is beneficial for those in situations warranting low cost visibility enhancement solutions, with further cost benefits likely as technology becomes more common and affordable. Areas experiencing high turnover, and thus large numbers of drivers inexperienced with particular routes, may also benefit from DGPS technology utilizing extensive digital maps. With some adjustments and through further testing of the current implementation, the DAS design will move closer towards these aspirations by making changes not only in how the system functions but also how it is implemented.

For starters, more needs to be done in order to warn and assist drivers when the system has or is just about to lose the GPS signal. It is also crucial that the HUD combiner screen become more stable. Furthermore, the DAS interface needs to make essential functions more accessible, as well as to make basic system functions more understandable for plow drivers. Components of the system should also be reevaluated as to their necessity to the DAS as a whole (e.g. radar) and eliminated if possible (e.g. audio lateral offset warnings). In this way, the DAS benefits from eliminating unnecessary and poorly functioning elements while improving upon a successful platform.

DESIGN RECOMMENDATIONS

The following recommendations for future versions of the DAS are based on both the FOT and track testing results.

Drivers who have used the system before this testing were impressed by improvements that have been made to the reliability and stability of the system. Those drivers new to the DAS appreciated the aid it provided that they had never experienced before. Even so, responses from the interviews suggest that there are some potential areas for improvement for the DAS.

The following recommendations have been sorted by their relative priority and severity, as defined on the following scale:

- **Cosmetic**: little effect on system usability
- **Minor**: likely to cause only short-term delays and frustrations
- **Major**: likely to significantly delay and frustrate users
- **Catastrophic**: prevents the use of the system

1. <u>Help compensate for the suddenness of GPS solution loss</u>: (Catastrophic)
   The DAS is very capable of interpreting and displaying for the driver useful information concerning lane position and safety hazards. However, this ability is compromised by the basis of its functioning: GPS signal reception (i.e. its "solution quality").

   It is understandable to lose the GPS signal on occasion; however, it presents the problem of keeping the driver safe and aiding their ability to guide the truck during these transitional, guidance-free periods. More effort should be spent to warn the driver of an upcoming loss of signal as well as providing some method of guidance in the interim between fixes. Solutions to this issue are currently being explored.

   An example implementation of this would be to actively alert the driver that GPS solution has been lost. As this happens, a backup lane position mechanism should be activated that, from the driver's perspective, functions and appears to be the same as the DAS. This will provide lane information (even if only a few seconds), thus allowing the driver a transition period before they have to navigate unassisted or with another backup lane assistive system.

Solutions to these issues are currently being explored by the design team.

2. Increase HUD combiner stability: (Major)
A frequent criticism and annoyance was the combiner vibrating out of position/alignment while driving. Though this was a recommendation in last year's field operation testing, it does not appear that the drivers are any more satisfied with this year's combiner.

   A more stable combiner-mount with adjustment options that are easier to find and to use have been recommended improvements and in fact a new implementation has been implemented in ongoing plow field studies using the DAS. Further evaluation of the stability and usability of this new combiner is now recommended.

   A redesigned combiner is currently being tested in several other plow field operational tests.

3. Use terms a driver would understand on the main panel of touch screen interface: (Major)
The term "solution quality" is a very technically laden term to have on an interface for plow drivers. Whether or not the user has been trained in the system, it is not as important for them to learn these solution quality numbers as it is to know when the system is functioning properly.

   Furthermore, the numbering system of a 0 for no solution, a four for "Fix", and a five for "Float" is counterintuitive to anyone not familiar with DGPS systems, especially someone merely glancing at the display while trying to do his or her job of plowing snow during low-visibility weather conditions.

   Therefore, if the original terms are to be maintained, it is recommended that drivers only be presented the relative terms of "Fix", "Float", "DGPS", and "Unavailable" or "No correction/signal" (or another brief message to convey this loss of signal). Any simple verbiage is appropriate, as long as it can be understood quickly and is already intuitive to most drivers.

   The newest version of the interface resides on a small PDA display. Because there is less information being displayed to drivers, it is even more critical that the information provided be informative and understandable. Further understandability and usability testing of this new interface is recommended.

4. Make adjustable lane boundary (offset) setting more salient: (Major)
Though drivers were taught in training how to adjust the lane boundaries (for instances of plowing shoulders or the centerline), they often complained when the warnings would go off while performing these tasks or felt it was too much bother to navigate the interface and make the adjustment while driving. Some drivers chose not to use the DAS in its entirety because they did not want to bother with this extra step of having to adjust the setting.

   It would make more sense to have this setting in a place where they can access it immediately, such as on the main interface page. Alternatively, it would be highly advantageous for this function to be available as a manual knob. Not only are manual knobs available in all interface modes, but also drivers may be able to reach for and adjust a physical knob without looking, whereas it would be quite difficult to navigate through and adjusting a "soft" interface without looking.

5. Eliminate/limit false positive radar targets: (Major)
   Drivers noted that at various times false radar targets would be displayed on the HUD, where no physical objects actually existed. If these occurred at certain stages of the route, experienced drivers became aware of them and got used to ignoring them.

   However, these are problematic for two reasons. First, drivers new to that route or area that are using the system will become confused or possibly even behave erratically in order to avoid these false targets. Also, drivers who become used to a warning may also have the tendency to ignore other target warnings, possibly even believing them to be false, when they may be real targets. It is also noted that false positive radar targets proliferate on curves due to the aiming of the radar.

   If the wing plow is not being used, it is recommended that the radar be focused only on tracking targets on the road and in the direct path of the plow instead of picking up possible targets on the shoulder. The ability to track targets on the right shoulder should then be enabled when the wing plow is down or enabled during times that the system senses the driver may need this function (e.g. times when the truck is plowing the shoulder).

   A treatment for these deterministic false radar targets would be to have drivers note and report areas where these instances are prevalent. A DAS enabled truck should then repeatedly drive the areas in question, noting the consistency of these false targets. The locations would then be noted in the database so that when the radar picks up these targets it prohibits the system from warning the driver. An alternative solution would be to display general directional warnings for targets outside of the HUD display, such as targets located next to the road.

6. Examine alternative HUD colors and cues that indicate distance: (Minor)
   Many drivers commented on not being able to translate the color differences in the HUD into real-life distances. Though it was explained to them in training, if the system set up in the HUD to portray depth cues is not memorable or translatable into a real world context, it is not effective. Additional training is highly recommended if the present implementation remains in the HUD.

   Alternatively, further testing is recommended on the current depth cue/color system and other alternatives to improve driver's understanding between real-world expectations and these indicators while being careful to provide only the most context-salient information. An additional recommendation is to replace the current absolute distance of 350 meters with lines in the HUD that gradually fade in brightness as the distance is further from the driver.

7. Improve accuracy in the relationship between HUD display and real world: (Minor)
   During the C and LV conditions of track testing, drivers seemed to think the lane center was left of where it really was. Yet, while using the DAS, drivers thought the center was to the right of center. This difference was consistent across both Straights, suggesting that there

may be an inconsistency between where the lanes are in the real world and where the lanes are being displayed in the HUD.

Whether this is a result of combiner alignment, driver perception, or drivers' strategic response to the high risk shoulder, this trend suggests an unwanted difference in performance is present. Drivers interactions with the physical components of the DAS (i.e. how drivers are aligning, setting up, and maintaining the combiner) should be studied and evaluated for trends that may lead to poor system performance.

In addition, the utmost care should be taken to ensure the lane center in the DAS matches the true lane center, and that the road is mapped correctly in relation to the road, otherwise the system will not be effective in notifying drivers of their location. Further and more frequent calibration checks are suggested.

8. Improve reliability of radar system: (Minor)
   Some drivers commented that when they had radar targets on the road ahead of them (even during clear conditions), the radar would sometimes register them and sometimes not. Though this functioning may be limited by the state of the art, solutions to this problem should be explored.

   Drivers experiencing such inconsistent behavior over time will learn not to trust the radar and in turn they may not trust the system as a whole. For this reason, it may be helpful for future teams to make a concentrated effort at maintaining the radar accuracy and alignment for consistent performance.
9. Use haptic seat to implement tape backup system: (Minor)
   If given the choice between the tape system and nothing, two thirds of the drivers would like to have some implementation of this system. Many of the drivers said that they'd like to experience the tape backup system warnings though the haptic seat, thus it is recommended to use the seat for future implementations of this warnings system.

10. Consider eliminating audio lane boundary warnings: (Minor)
    A useful warning needs to grab the driver's attention and tell them pertinent information about the driving environment, while not being so obnoxious as to startle drivers or cause them to ignore or turn off the warning. Since it seems that drivers feel highly ambivalent towards this warning system (and even feel animosity towards its functions), it is recommended to have this warning be defaulted to "off" unless a driver specifically asks to turn it on, or to remove it from the system completely.

11. Adjusting HUD combiner brightness: (Cosmetic)
    An infrequent comment was that the brightness of the combiner was incorrect, and drivers did not know or could not find the brightness adjustment. Though shown where this adjustment was during training, drivers had a difficult time finding it in a practical setting. A more salient and easier to find brightness adjustment is recommended.

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APPENDIX A – CONSENT FORM

The consent form used for the Field Test was also used for the Track Test.

UNIVERSITY OF MINNESOTA
CONSENT FORM[1]
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.

Nic Ward and Mick Rakauskas, 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. This course and the duration of your drive will be defined by Mn/DOT as part of your usual working shift.

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.

We may want to use one or two brief video extracts from you driving 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 Mick Rakauskas, 111 Church Street S.E., University of Minnesota, Minneapolis, MN 55455. Phone: 612-624-4614.

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 ____________________

Page 1 of 1
Nov 15, 2002

[1] This is the same consent form as used for the prior operational test (0105S99101)

Appendix B – Snow Plow DAS Handbook

The following material was given to the drivers at the beginning of the FOT. It was given in a three ring binder with an index and tabbed pages for each section.

Sections that are presented elsewhere in the report are not included in this Appendix. Instead, the location of where this material may be found is listed.

Snow Plow DAS Handbook

Feel free to ask questions at any time during the study.
Use this guide to find the appropriate person to contact.

Contact Information:	…Can Answer Questions About:
John Scharffbillig Mn/DOT Cell: (612) 670 – 0594 Home: (651) 452 – 3501 Office: (651) 215 – 0402	- Administrative Issues - General Truck Station Issues
Craig Shankwitz University of Minnesota (612) 625 – 0323	- System Functioning - Technical Issues
Mick Rakauskas University of Minnesota (612) 624 – 4614	- Interviews and Questionnaires - Study Procedures

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If you have any questions or concerns about the study and would like to talk with someone other than the above research scientists, contact:

Research Subjects' Advocate Line
D528 Mayo
420 Delaware Street SE
Minneapolis, MN 55455

(612) 625 – 1650

Attention Plow Operators:
Subject: This Handbook & the SafePlow Driver Assistive System Research

We would like to thank you for being a part of this important evaluation of the SafePlow Driver Assistive System (DAS). Your contributions and frequent input during this winter season will be critical to this evaluation and the proper implementation of this system.

To make sure that we get the necessary information to improve the system, this handbook has been provided to you to help you understand the procedures we are using to collect data. You will also find a copy in your station and a quick reference card in the plow.

Everything that is explained in this handbook will be taught to you during your training. The handbook is meant to be a resource to use after training. In it, you will find:

- Contact information, if you have any questions, problems or concerns, please feel free to use the contact information on the title page of this handbook
- A copy of the consent form you have already signed, containing an explanation of what will happen during the study and additional contact information
- DAS Operation Instructions
- Pictures of the system's panels (a.k.a. screens) along with explanations of what they mean and how they are to be used
- Information on the study, what information is being collected by the plow and how it will be used by the researchers
- Interview questions, the list of questions that you will be asked by the interviewer
- End of study questionnaire, the survey that you will be given once the season is over

Again, thank you for your participation in this evaluation. If you have any questions, feel free to contact me using the information below (or on the title page of this handbook).

Thanks,

Mick Rakauskas
HumanFIRST Program
111 Church Street SE
Minneapolis, MN 55455

(612) 624-4614

(The **Consent Form**, which can be found in Appendix A, was included here)

SafePlow Participant Overview and Instructions

Use of the Driver Assistive System (DAS) will be evaluated from December 23rd, 2002 until March 31st, 2003. During this time we will be gathering driving performance data from the plow itself as well as subjective data on your opinions and ideas about the system. When the evaluation is completed, you will fill out a survey based on your experience with the system.

> **Note on Privacy:** Only the researchers will see the data that is collected. Your name and identity will not be connected to any piece of data, including audio and video recorded in the plow. Methods like the ones in the pictures below will be used to hide your identity.
>
> The researchers are looking to see if using the system helps to improve safety during low visibility conditions. They are also looking for input into how the system can be improved, as determined by your opinions and suggestions.

Measures of Driving

While you use the DAS, a number of different measures will be recorded.
Driving performance measures will be collected with the following methods:

- Steering / Lane Position
- Speed / Pedals
- Critical Incidents
- Productivity

In addition, audio and video will be recorded the entire time that you are driving on the highway. The four views that the video will be recording are shown.

Your Opinions and Suggestions

Your opinion is very important to us, so it is necessary for you to understand how we are planning to gather your opinions and comments about the DAS. During this season, we will be collecting information from you in a number of ways, as listed below.

Questions While Driving:
At certain times while you drive, the system will ask you a few questions by displaying them on the DAS screen. These questions relate to how much effort you are exerting while plowing at that moment.

> **Remember: <u>Your Main Responsibility is to Drive Safely</u>**
> It is more important for us that you drive safely and that you don't injure yourself and others on the road than it is we collect your responses. **Do not respond** to questions if you do not feel it is safe to do so.
>
> If the system starts to ask you questions while you are encountering dangerous driving conditions, **you should not answer the questions at that time!** Continue driving until you feel comfortable and then attempt to answer the questions if you feel it is safe.

Regular Interviews:
Once a month, you will meet briefly with Mick Rakauskas (612) 624 – 4614. During these meetings, you will be asked the questions found in the **SafePlow Interview Form** section of this handbook. During the interview, we will also discuss problems, concerns, or ideas you have about the DAS.

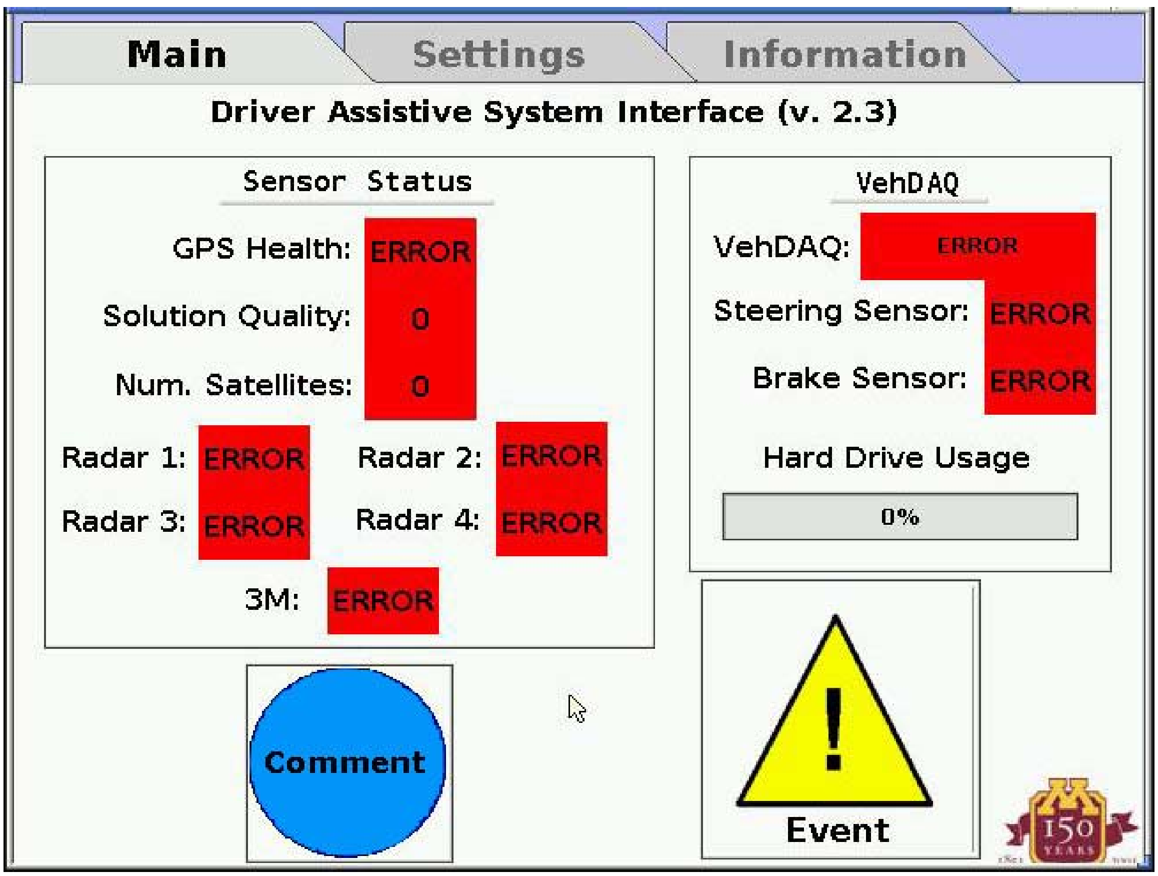
End of Season Survey:
Once the study is completed, you will receive a small set of questions to answer about your experience with the DAS. You will find these questions in the **End of Season Survey** section of this handbook. If you have any concerns or questions about this survey, feel free to contact Mick.

Driver Initiated Data

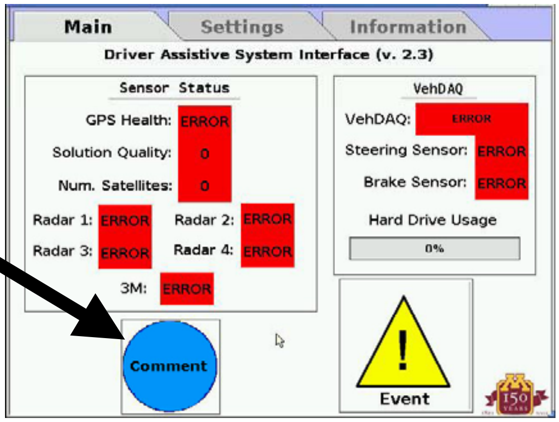
The following pages have pictures and explanations of all the panels you can operate while using the SafePlow Driver Assistive System (DAS) to record your opinion and answer questions about the system. These include images and explanations of the questions you will be asked to answer while driving.

The Main System Panel is made up of four parts:

- **Sensor Status** – displays how the elements of the system are currently operating.
- **vehDAQ –** stands for **Vehicle Data Acquisition,** displays how elements of data collection are currently operating
- **Comment Button** and **Critical Incident Button** – buttons on the screen that you may press to tell the researchers about situations while driving. These are described on the next two pages.



Comment Button



This button is a blue circle, and is labeled "Comment". It is located on the bottom left of the Main System Panel.

Press this button if you want to report any comments, problems, or concerns about the DAS. This includes any comments on the panels, audio and seat warnings, and lane position indicator.

After the button is pressed, explain your comments out loud. Your response will be recorded automatically to an audio file.

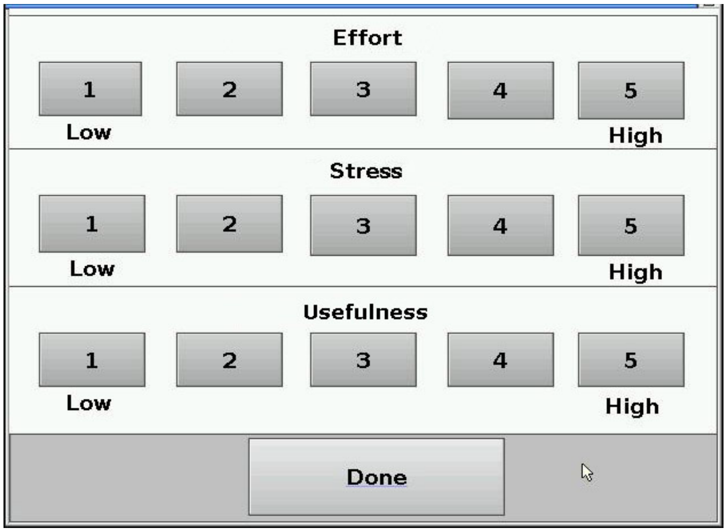
Then the panel will ask you a few questions about your driving experience. These questions are shown in the panel below. Questions will be displayed on the screen for a few minutes, then the Main System Panel will return. This gives you enough time to make your comments and navigate through any difficult situations and still have time to give your feedback.

You will be giving a rating for each of these questions:

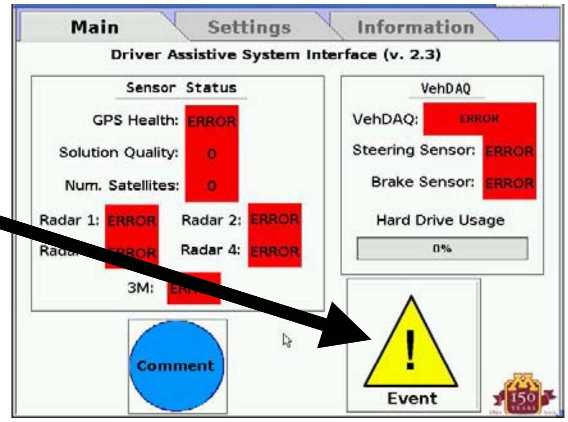
- How much <u>Effort</u> are you putting into driving?
- How <u>Stressed</u> are you?
- How <u>Useful</u> is the system? (Note: This question will be asked only if the system is operating)

Your rating will be on a scale from 1 to 5. A rating of 1 means "Low" and a rating of 5 means "High." Give a rating by pressing the numbered box that corresponds to your answer.

Pressing the "Done" button at the bottom will close these questions and return you to the Main System Panel. You may also hit the "Done" button at any time to skip the questions and return to the system.



Event ("Critical Incident") Button



This button is a yellow triangle with a "!" inside of it. Underneath it is labeled "Event". It is located on the bottom right of the Main System Panel.

Press this button if you encounter a dangerous or hazardous driving event, such as a near-miss with another vehicle or object on the road. This will tell us when this event happened.

You should also explain out loud what had just happened. Your response will be automatically recorded to an audio file.

Special Note: The automatic lane deviation alarm and seat warnings may go off when you think you are driving safely within your lane.

- If this is happening because the displayed lanes are not lined up with the actual lanes**,** adjust the Lane Offset in the Settings Panel accordingly (see page 10 for instructions).

- If this is happening because the warning is too sensitive, press the Comment button and then tell us out loud why you think the warning is not correct (see page 8 for instructions). We will listen your responses and see if we can fix the problem.

System Initiated Data

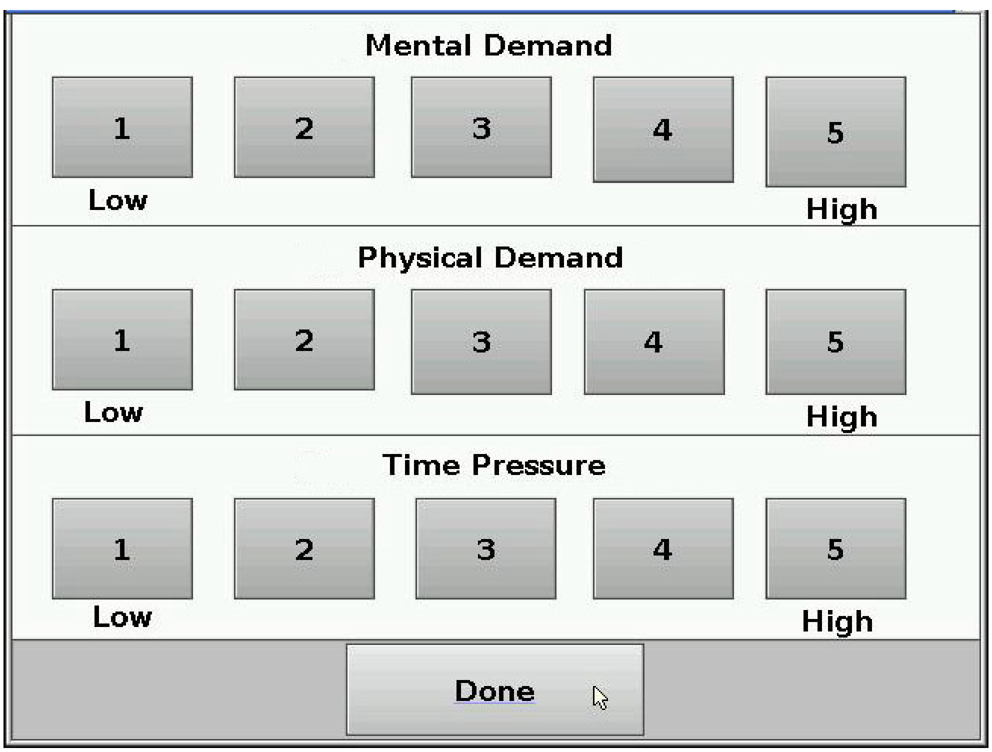
At certain times while you drive your route, you will hear a tone. This signifies that the system is requesting data from you. At this time, the panels of questions that are shown below will be displayed. They will appear whether you are using the system or not.

The questions are displayed in a series of 2 panels, as seen below. Each question is asking you to rate how much of each type of effort you are giving at that moment. The types of effort are:

Mental Demand – How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the route to this point easy or demanding, simple or complex, exacting or forgiving?

Physical Demand – How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the route to this point easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

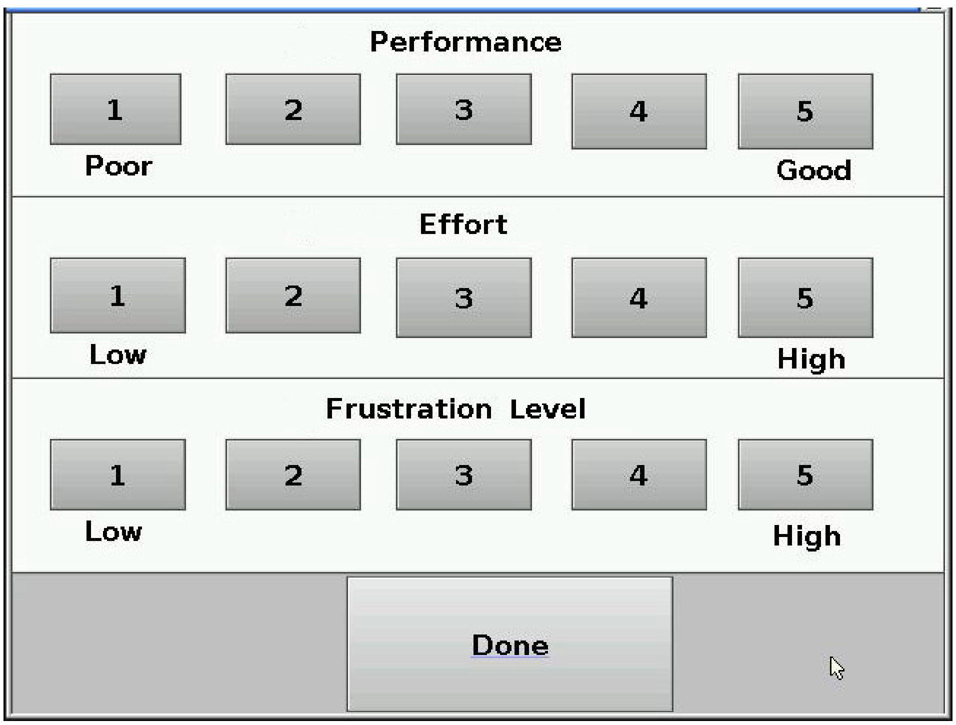
Time Pressure – How much time pressure did you feel due to the rate or pace at which events occurred? Was the pace slow and leisurely or rapid and frantic?



Performance – How successful do you think you were in accomplishing the goals of plowing and safely driving? How satisfied were you with your performance in accomplishing these goals?

Effort – How hard did you have to work (mentally and physically) to accomplish your level of performance?

Frustration Level – How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the route up to this point?



Your rating will be on a scale from 1 to 5. A rating of 1 means "Low" and a rating of 5 means "High."

To give a rating, press the numbered box that corresponds to your answer. Once all the questions are answered, press the "Done" button to advance to the second page of questions, and to finish once all the questions have been answered.

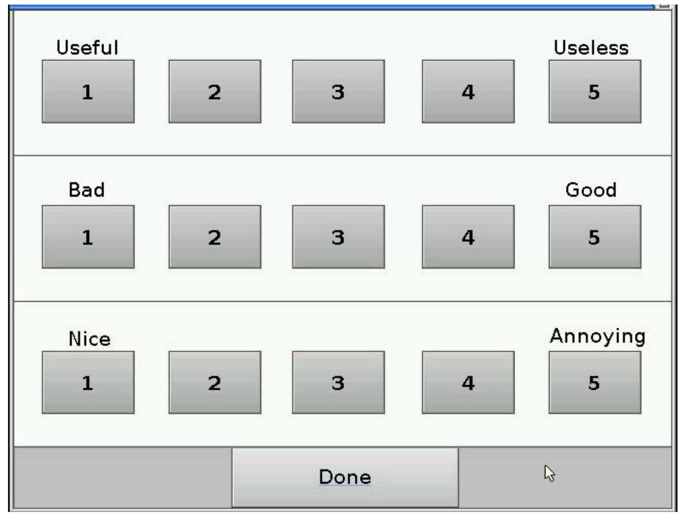
Pressing the "Done" button will close the current panel of questions whether they are answered or not.

End of Route Procedures

Just as you are returning to the depot, you will hear a reminder that there are questions to be answered before shutting down your plow.

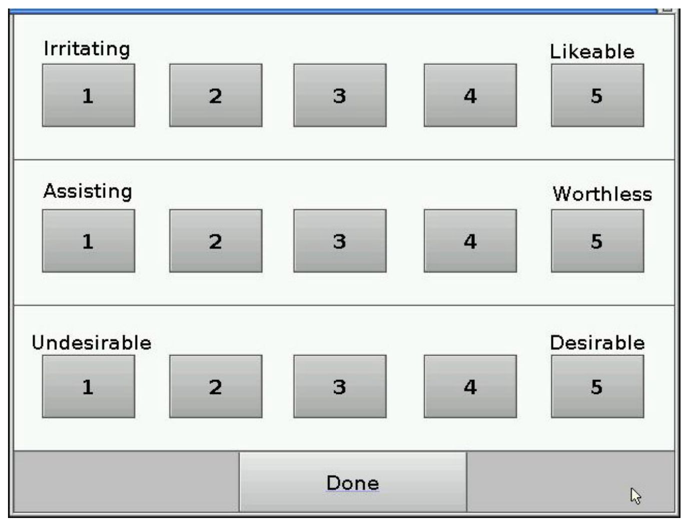
After you park the plow, do not shut off the engine or turn off the system until you have answered the questions on the screen.

The questions appear as a series of 3 panels, as seen here. Each question is asking you to give your opinion of the system, using a rating scale of one to five between two descriptive words.

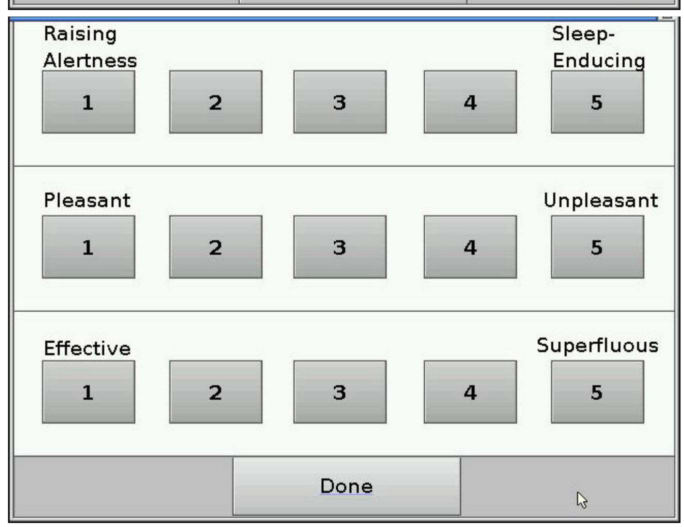


To give a rating, press the numbered box that corresponds to your answer.

- For example, if you thought the system was very useful, you may press the “1” box closest to the word “Useful.”
- In the next row down, if you thought that the system was somewhat “Good”, but definitely not “Bad”, you may press the “4” box.
- Then, if you found the system to be neither “Nice” nor “Annoying”, you may press the “3” box in the middle.

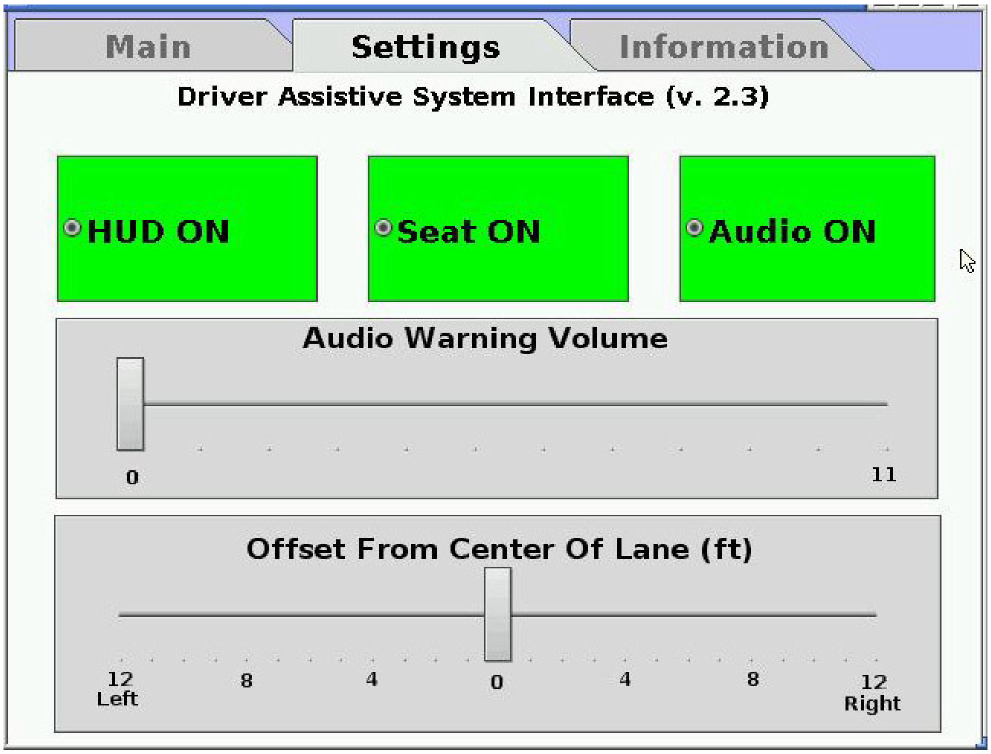


After you have completed the three questions, press the “Done” box in the bottom to continue to the next panel, until you have completed all three panels.



Settings Panel

This panel has three on/off buttons at the top and two sliders to adjust audio and lane offset. You may change these settings to suit your own personal preferences. It is advised that you do this before leaving the depot.



For the three buttons, if the button says "ON" and is green, then that system is enabled. If the button says "OFF" and is red, the system is disabled. The systems are:

- **HUD** – the Head Up Display (HUD). When the HUD is on, you will see the highway road lines on the combiner (when the combiner is in the down position).
- **Seat** – The seat vibration feedback. When the Seat feedback is on, the sides of your seat will vibrate when you go outside of the lane.
- **Audio** – the in-cab audio warning. When the Audio feedback is on, a noise like a rumble strip will be heard when you go outside of the lane.

Audio Warning Volume – sets the volume of the warning speakers. Press the screen to the left or to the right of the slider to change the volume. Moving it to the left will lower the volume, moving it to the right will increase the volume.

Offset from Center of Lane (ft) – if you think that the lane centering measure is not accurate, you can adjust it here. Press the screen to the left or to the right of the slider to change where the system determines the center of the lane should be. For example, if the system continuously says that the center of the lane is about two feet to the left of where it actually is, move the slider to the left to the position between the "4" and the "0".

Interview Questions

Once a month, you will briefly meet with Mick Rakauskas (612) 624 – 4614. Meetings are expected to last about 20 minutes.

The bulk of this meeting will consist of answering the questions on the following pages. For example, you will be asked to talk about:

- Your experiences with the DAS
- Problems you've had, and anything out of the ordinary
- Suggestions you have to improve it
- Concerns you have of participating in this study.

During the meeting, the questions will be asked to you and you will discuss your answers with Mick. You will not be answering the questions on paper.

Mick will work to schedule meetings so that they are convenient for you. He also understands that conflicts do come up unexpectedly. If you cannot make a scheduled meeting, make sure to contact Mick as soon as possible.

Please read though the questions on the following pages before your first interview meeting so that you are familiar with the type of information that will be discussed.

(The **Interview Questions** can be found in Appendix F)

(The **End of Season Survey** can be found in Appendix G)

APPENDIX C – QUICK REFERENCE CARDS

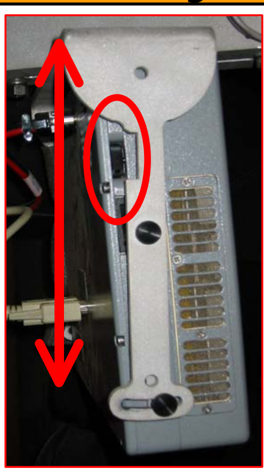
Card 1, Side 1: Main Panel: Sensor Status

Main Panel: Sensor Status

Sensor Name	Status	What it Means
GPS Health:	OK	Receiving GPS information
	ERROR	Not receiving GPS information
Solution Quality:	4	2 in. - 4 in. position accuracy ("Fixed")
	5	4 in. - 10 ft. position accuracy ("Floating")
	0 or 2	Not enough info. to tell where you are
Num. Satellites:	#	Receiving information from # satellites
	0	No satellite information is being received
Radar #:	OK	Radar # is active
	ERROR	Radar # is inactive
3M:	OK	Magnetic lane position is available
	ERROR	Magnetic lane position is not available

Card 1, Side 2: Brightness Adjustment & Settings Panel

Brightness Adjustment & Settings Panel



To Change the HUD Brightness

Turn the control on the far (passenger) side of the projector UP or DOWN

Setting:	What it does:
HUD	Turns ON/OFF Head-Up Display
Seat	Turns ON/OFF the vibrating seat lane position warnings
Audio	Turns ON/OFF the audio lane position warnings
Audio Warning Volume	Adjusts the volume of the audio lane position warnings from 0 to 11
Offset from Center of Lane (ft)	Adjusts where the DAS thinks the center of the lane is (adjust if innacurate or if plowing shoulder)

Card 2, Side 1: Comment & Event Buttons

Comment & Event Buttons

Button	When to Press	What it Does
Event	After a dangerous driving event, such as a near-miss with another vehicle or object on the road	Marks event in the data file Records out-loud comments
Comment	When you want to report problems, comments, or suggestions about the DAS	Records out-loud comments Brings up a panel of questions

Comment Questions:

Effort:	How much effort are you putting into Driving?
Stress:	How stressed are you?
Usefulness:	How useful is the system?

After pressing a button, say your comments clearly

Card 2, Side 2: How to Answer Panel Questions

How to Answer Panel Questions

Type	You'll Hear	Instructions
Pop-Up appears mid-route	A short warning tone	On a scale of 1 (low) to 5 (high) rate how much effort you are giving in the following categories:

Mental Demand	thinking, deciding, remembering, looking, searching, etc.
Physical Demand	pushing, pulling, turning, controlling, activating, etc.
Time Pressure	was the pace slow & leisurely or fast & frantic?
Performance	how successful were you in plowing & driving safely?
Effort	how hard did you work to perform at this level?
Frustration Level	how discouraged, irritated, stressed, annoyed do you feel?

Type	You'll Hear	Instructions
End of Route when return to station	Warning that you're nearing the station	Give your opinion of the system by pressing a rating between the two descriptive words.

DO NOT Shut off the Plow until these questions are answered

APPENDIX D – MENTAL WORKLOAD MEASURES

The following set of questions are cycled through the LCD panel at the midpoint on both directions of the operational route. At each point, a tone signaled the change in the panel to data input mode and the display shifted through a series of screens with the following questions (definitions and instructions were given to drivers in advance):

- Mental Demand
- Physical Demand
- Time Pressure
- Performance
- Effort
- Frustration Level

These items are based on the NASA-RTLX (NASA Raw Task Load Index), a reliable measure of mental workload (Moroney et al. 1992), but converted to a 5-point scale to simplify the response input. Each panel is closed with the 'done' button is pressed, or after five minutes have elapsed. This gives the option for the driver to exit without completing to return to the system display.

All questions besides "Performance" were scaled from "Low" = 1, to "High" = 5. Performance was scaled from "Poor" to "Good." These questions relate to the overall response of the driver to the driving conditions and system performance. It does not provide direct comment about the system itself.

APPENDIX E – USABILITY QUESTIONNAIRE

Van der Laan, Heino, and de Waard (1997) proposed the following usability scale for the acceptance of a system. It allows the researcher to determine a Usefulness and Satisfaction score for the system used. The system uses the following antonym set-up from which the participant is to mark their agreement:

Rate your judgment of the system for each descriptive term below:

Useful	☐	☐	☐	☐	☐	Useless
Bad	☐	☐	☐	☐	☐	Good
Nice	☐	☐	☐	☐	☐	Annoying
Irritating	☐	☐	☐	☐	☐	Likeable
Assisting	☐	☐	☐	☐	☐	Worthless
Undesirable	☐	☐	☐	☐	☐	Desirable
Raising Alertness	☐	☐	☐	☐	☐	Sleep-inducing
Pleasant	☐	☐	☐	☐	☐	Unpleasant
Effective	☐	☐	☐	☐	☐	Superfluous

The format is similar to previous FOT on-screen reporting (Appendix B) with five response buttons, but the scales are anchored by antonyms (good-bad) rather than levels of the construct (low-high), as seen above. There are three panels of three items since the driver should be parked to complete this series. These questions are presented when a driver returns to the station.

Although using the panel can provide data in the immediate context of use, the simplified method of response input limits the extent of information that can be collected. To get more information from the driver about the overall experience with the system, it was also necessary to conduct structure interviews and debriefing questionnaires.

APPENDIX F – INTERVIEW QUESTIONNAIRES

The experimenter posed the interview questions to the operators aloud during regularly scheduled interview sessions. For the majority of questions, the operators were asked to rate their agreement to statements on this scale:

1	2	3	4	5
Strongly Disagree	Disagree	No Opinion	Agree	Strongly Agree

A large printed version of the scale was given to the drivers to refer to while answering these questions.

In the list below

- Yes/No questions are followed by "(yes/no)"
- Open ended questions are followed by "(open ended)"
- Forced/ Multiple choice questions are followed by their respective answers in parentheses

Interviews were conducted at the driver's stations on a monthly basis. The questions and instructions were as follows:

The following statements ask you to compare driving with the Driver Assistive System (DAS) to driving unassisted. Indicate the number that tells how much you agree or disagree with each statement.

1. I felt more comfortable while using the DAS.
2. The DAS distracted me very much.
3. Using the DAS made me feel safer.
4. Using the DAS while driving took a lot of effort.
5. I often relied on the DAS for guidance in maintaining lane position

The following statements ask you about your opinion of the Driver Assistive System (DAS). Indicate the number that tells how much you agree or disagree with each statement. Further questions may follow.

6. The DAS provided me with reliable information.
7. I trusted the DAS to provide me with accurate information.
8. The DAS was useful in good visibility.
9. The DAS was useful in poor visibility.
10. I had confidence that the DAS would help me maintain my lane position.
11. I trusted the DAS to help me maintain lane position, as compared to trusting my own abilities.
    a. If you had trouble trusting the DAS (≤ 3), what were your reasons for this? (open ended)
12. Remembering how to use the DAS was difficult.
    a. What have you learned from using the DAS that you <u>should have been told</u> before using it? (open ended)
13. Using the DAS made me a safer driver.
    a. In what ways? (open ended)
14. Using the DAS improved my plowing performance.

    a. How? In what ways? (open ended)

15. The DAS provided useful information in addition to my traditional visual cues.
    a. What was most useful to you/what would be your ideal configuration? (open ended)
    b. What parts of the current DAS should be removed? (open ended)
    c. What things would you like added to improve the DAS? (open ended)
16. It was easier for me to drive while using the DAS.
    a. Why?
17. I was satisfied with the overall performance of the DAS.
18. Would you like to have the DAS permanently installed in your truck? (yes/no)
19. Would you recommend that Mn/DOT install the DAS in all plows? (yes/no)
    a. Please explain your recommendations… (open ended)

APPENDIX G – FINAL SURVEY

The final survey was administered after all of the Track Testing conditions were completed.

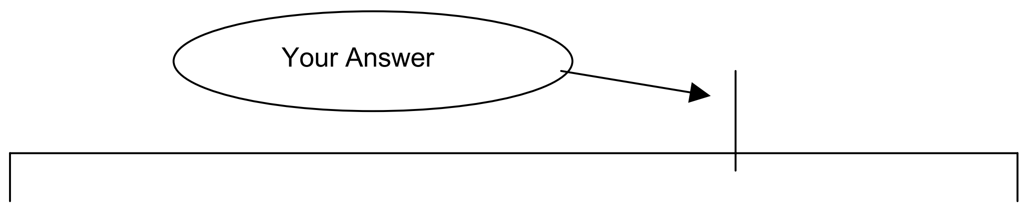
Final Survey

The following packet asks you to answer some questions based on your experience with the Driver Assistive System (DAS) this evening. The types of questions asked will include:

- Questions asking you to rate your opinion of a statement on a scale.

Following a question or statement, you will see a scale that allows for a range of possible answers. For each question, make a mark on the scale in the place that best indicates how you feel about that question.

Example: How important are seat belts in driver safety?



Not at all Important | Very Important

Comments: ____

- Yes / No questions

Example: Would you recommend the DAS to other drivers?

Yes ________

No _________

- Open ended questions

Example: Do you have any suggestions for how the DAS could be improved?

____

____

The following questions are about the usefulness of the Driver Assistive System (DAS) during limited visibility conditions (tinted windows and low headlights).

1. In general, how useful was the DAS?

Not at all Useful — Very Useful

2. How useful were the lane markings on the head-up display?

Not at all Useful — Very Useful

3. How useful was it to see objects ahead (radar squares) on the head-up display?

Not at all Useful — Very Useful

4. How useful were lane departure warnings?

Not at all Useful — Very Useful

5. How much did you trust the DAS?

Not Trust At All — Trusted Very Much

6. How much did you rely on the DAS?

Did Not Rely on it | Relied on it Very Much

7. How much confidence did you have in the DAS?

No Confidence | Complete Confidence

8. How stressful was it to use the DAS?

Very Stressful | Not at all Stressful

9. Did you feel that you needed breaks more often than usual when using the DAS?

Yes ________

No _________

10. Were you more fatigued than usual after using the DAS?

Yes ________

No _________

The following questions are about the lane departure warning system of the DAS.

11. How much did you like the center and end-lines changing color to red (on the head-up display) as a lane departure warning?

Dislike Very Much — Like Very Much

12. How much did you like the rumble strip sounds as a lane departure warning?

Dislike Very Much — Like Very Much

13. How much did you like the vibration at the edge of the seat as a lane departure warning?

Dislike Very Much — Like Very Much

14. The lane departure warning system is a combination of the red road lines (on the head-up display), the rumble strip sound, and the vibrating seat. Would you prefer another type of warning?

Yes ________

No _________

If you answered "Yes": How should the warning be given?

The following questions ask about the hardware used for the head-up display.

15. How comfortable were you with where the head-up display ("combiner") was placed?

Very Uncomfortable Very Comfortable

Comments? ____

____

____

____

16. How comfortable were you with where the projector panel was placed?

Very Uncomfortable Very Comfortable

Comments? ____

____

____

____

For this testing, you experienced an <u>early version</u> of the DAS. The following questions are about the <u>final version</u> of this system that will be available in the future.

17. Would you like to have the final version of the DAS permanently installed in your vehicle?

    Yes ________

    No _________

18. Would you use the final version of the DAS if it were permanently installed in your vehicle?

    Yes ________

    No _________

19. Would you recommend the DAS to other drivers?

    Yes ________

    No _________

20. If it becomes technologically possible, would you like to see the oncoming traffic in the opposing lane on the head-up display?

    Yes ________

    No _________

21. Do you have any suggestions for how the DAS could be improved?

____

____

____

____

22. This page is for any comments you may have about your experience of driving with the DAS and Tape systems.