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Final Report

System Performance and Human Factors Evaluation of the Driver Assistive System (DAS): Supplemental Track Test Evaluation

Intelligent Vehicle Initiative
Specialty Vehicle Field Operational Test

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16. Abstract (Limit: 200 words)

This track test supplements an attempted field operational test (Rakauskas et al., 2003) which did not provide enough experience using the Driver Assistive System (DAS) during low-visibility conditions to make reasonable conclusions on driving performance. This study aimed to determine the usefulness of the DAS in the context of simulated low-visibility conditions. Drivers drove in clear, low-visibility, and DAS-assisted low-visibility conditions. Driving performance measures were taken while driving and drivers were asked workload, trust, and subjective response questions after each condition and post-experiment. The DAS enabled drivers to maintain consistent lane position and to make fewer steering corrections than while driving the low-visibility condition. Using the DAS during low-visibility conditions did not change speed performance and aided the driver by providing additional information about the road. More mental effort was reported while assisted by the DAS 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. 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. We encourage further research with the DAS on larger numbers of drivers or in a more powerful study design. Some changes are also recommended for future versions, such as providing a warning prior to loss of GPS fix.

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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 on a track test. After the researchers and Mn/DOT decided that a field operational test (FOT) did not provide the snowplow operators with enough experience using the DAS during low-visibility conditions due to an absence of snowfall, they felt that 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.

For this 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 between the DAS and 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.

The objectives of Safety and Acceptance were focused upon 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 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

This project is a study to determine the usefulness of the Driver Assistive System (DAS) in context of plowing roads during low-visibility conditions. This is the fourth component of the Intelligent Vehicle Initiative Specialty Vehicle Field Operational Test, sponsored by Mn/DOT.

An 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. An overview of the DAS, a review of the Intelligent Vehicle Initiative Specialty Vehicle project background, and the findings of this FOT can be found in the companion document (Rakauskas et al., 2003).

Mn/DOT and the researchers decided in mid-February that the FOT would not provide enough experience using the DAS during low-visibility conditions due to an absence of snow. 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 purpose of this document is to discuss the objective and subjective data from this track test.

CONSIDERATIONS

Two general methodological approaches can be taken in the design of the test track experiment. Both are based on the theoretical model of the driver and task performance presented in Figure 1.1. In this model, a task is seen as having a continuum of demand on the driver to apply resources (effort) to achieve operational goals. The driver will recognize increased task demand and apply greater effort. However, because humans have limited resources, there will be a point where no more effort can be generated. At this threshold, performance becomes more variable and may decline, with a probability of reduced safety and productivity.

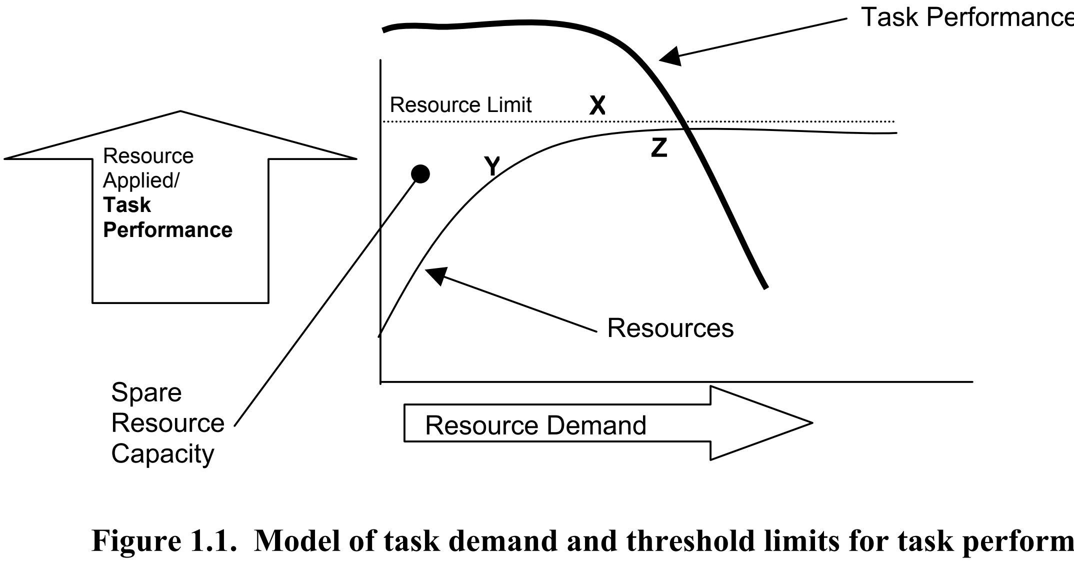


Figure 1.1. Model of task demand and threshold limits for task performance.

First (Methodology A), it can be assumed that the system functions as a support system and reduces resource demand by making the task less difficult for the driver (Point X to Point Y). In this case, the system benefit would be evident from a reduction in driver effort and an improvement in level and variability of task performance.

Based on this approach (A), measures of driver effort and performance (impairment) would be collected in a study designed with conditions depicted in Figure 1.2. As can be seen, driving in fair visibility and without a system is predicted to show the least amount of impairment to drivers, while driving in poor visibility without a system is predicted to show the most impairment. Driving with an assistive system is predicted to help drivers overcome some of the impairment added by poor visibility, with the DAS alone helping more than the DAS while transitioning to the 3M system (as in Transitions Between Two Systems – Poor Visibility). The reasoning behind this is that the driver is using the HUD and interface similarly, but he or she now has to comprehend and switch between two modes of information.

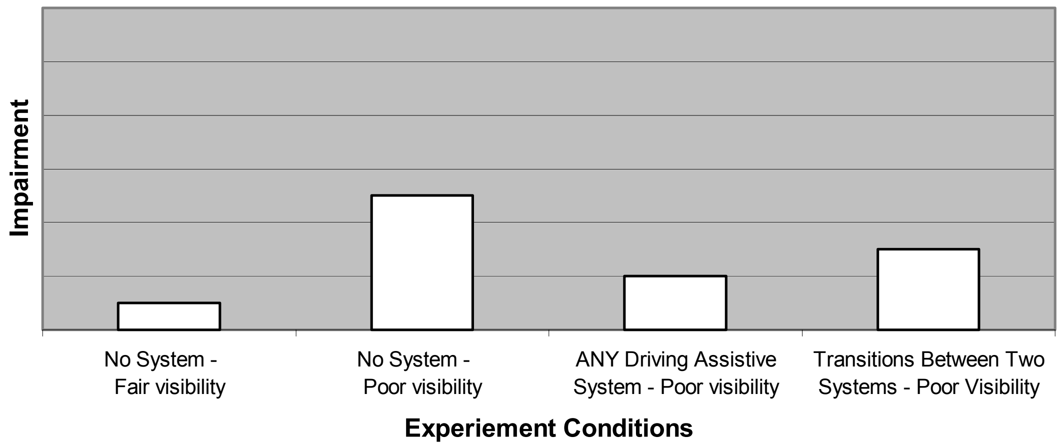


Figure 1.2. Experiment condition based on Methodology A to assess system benefit as reduction in resources with reduced effort and improved performance.

Second (Methodology B), the same model can be used to examine the spare resource capacity provided to the driver by the use of the system (see Figure 1.1). This spare capacity is the amount of extra resources a driver has in reserve to apply to additional and unexpected demands during the plowing task (Y). This concept is critical to safety because it is the buffer that accommodates changing events in the operational context.

Based on this reasoning, the experiment could be designed to see if the driver can be loaded with additional task demands and measure the available increase in effort and amount of impairment in performance. With reference to Figure 1.3, the system benefit would be evident due to an ability to successfully accomplish the additional (load) task with less overall effort and impairment (Y to X). In other words, the system would 'protect' the driver in the presence of secondary task loading that may otherwise be a risk factor (X to Z).

Based on this approach (B), measures of driver effort and performance would be collected in a study designed with conditions depicted in Figure 1.3. These predicted levels of impairment follow the same reasoning stated for Figure 1.2.

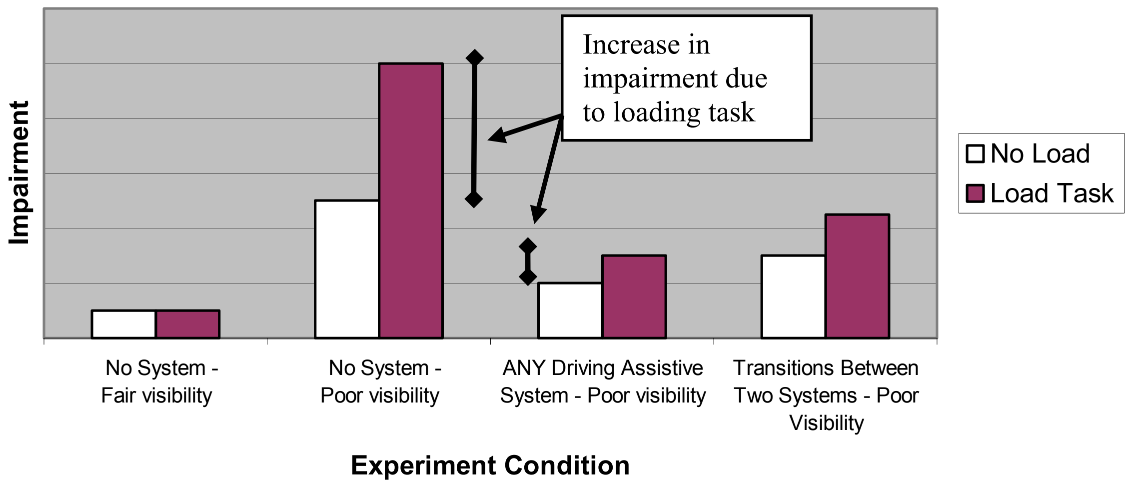


Figure 1.3. Experiment condition based on Methodology B to assess system benefit as reduction in the interference from an additional loading (distraction) task with increased effort, but no reduction in performance.

For both methodologies, performance would be based on driving tasks on the track that are (i) representative of a range of skills used in operational plowing, and (ii) logically relevant to productivity measures. Primarily, these will be based on the accuracy and variability of lane position and speed control.

Also, the following comparisons are advocated in the study design for both methodologies:

- (No system – Poor visibility) versus (Driving Assistive System – Poor Visibility): Effect of system in the conditions it is intended to benefit.
- (No system – Fair visibility) versus (Driving Assistive System – Poor Visibility): The relative benefit of the system with reference to ideal performance.

Note that the experimental design for Methodology B subsumes the design for Methodology A (i.e., the unfilled bars in Figure 1.2 and Figure 1.3). However, methodology B is more informative because it demonstrates the potential effect of the system to reduce driver effort and improve performance, but in addition examines these effects under high workload conditions that may pose the greatest risk in terms of operational conditions.

Due to scheduling and time constraints, a third methodology (Methodology C) was used, combining advantageous aspects of Methodologies A and B. The four conditions (good visibility, low visibility, low visibility with DAS, low visibility with 3M transitions) were never presented without the loading task from Methodology B, thus inducing higher workload conditions for all of the trials. Therefore, the four conditions were: Control (C), Low Visibility (LV), Low Visibility with DAS (DAS), and Low Visibility with 3M Transitions (TRAN).

Figure 1.4 shows a number of alternative methods to simulate poor visibility on an arbitrary continuum of realism with respect to actual snow conditions. Note that we focus on snow for visibility rather than for plowing.

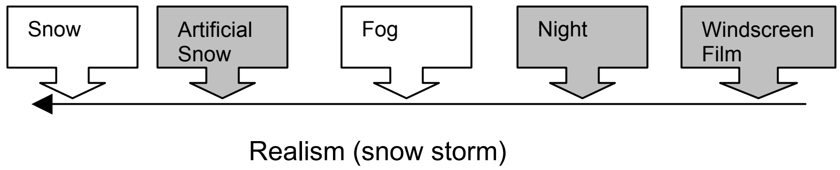


Figure 1.4. Continuum of alternative methods to simulate poor visibility.

It was desirable to have a test track study that resembled actual operating conditions as closely as possible. If the most realistic alternative was explored initially, then other options could be adopted later if necessary. Therefore, it was originally proposed that the track study would adopt the most realistic condition by exploring the feasibility of using artificial (foam) snow. For various reasons the foam snow system was deemed inadequate for our purposes (for details see Appendix A). Alternative measures, such as testing at night with tinted film on the windows and headlight blinders, were used instead to simulate realistic conditions for this evaluation.

Objective

Consistent with the original operational test, the track study had the following objectives identified by Mn/DOT:

- **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, enabling the system for operating conditions and setting up 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.

- **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).

- **Acceptance** – The acceptance of the system by drivers is critical both to safety and deployment. In the operational test, driver acceptance was measured by a variety of self-report measures at different phases of the project. The test track study used the same comprehensive set of measures, although the wording and timing of these was modified. Thus, driver acceptance remained a priority issue for the track study.

- **Reliability** – The operation of a system should robust and maintainable. A system that operates unreliably will lack 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.

Due to the differences between track testing and field testing, not all of the above objectives could be explored in as full detail in the track test as they were in the FOT. For example, the drivers' objective performance on the test track primarily focused on the Safety objective and was quantified by using four measures of driving performance. Also, the drivers' subjective results from the track test mainly focused on the Acceptance objective and were quantified through questionnaires and interview sessions. Questions dealing with Operability and Reliability of the DAS were included as well but are explored in less detail.

Advantages

There are a number of significant advantages of designing 'experiments' on a test track relative to natural 'observations' during actual operations:

- **Control** – Experiments have control over other factors that might hide or confound the 'true' effects of the system.
- **Precision** – Experiments can include carefully defined tasks with comprehensive data so that the effect of the system on the task can be interpreted and explained.
- **Compression** – Experiments can create and expose drivers to events that are relevant to the evaluation of the system, but do not occur with a high frequency to observe them in operational context.
- **Replication** – Experiments can repeat the conditions for the same driver, or for different drivers in the test sample to ensure sufficient and similar data points for analysis.
- **Standardization** – Experiments can repeat these conditions in the same manner for all cases to ensure the identical experience for all drivers, thereby reducing variables that may hide or confound the "true" effect of the system.

2 METHODOLOGY: TRACK TESTING

The test track study used an experimental method with snowplow operators driving trucks enabled with the DAS and 3M magnetic tape system. Operators drove a plow truck on a predetermined course while having their view limited by a combination of shaded film on the windshield and windows, and filtered headlight illumination. Participants were subjected to nighttime low-visibility conditions similar to what drivers might encounter during the field operational testing on Highway 7.

PARTICIPANTS

The experimental sample was comprised of ten Minnesota Department of Transportation snowplow operators assigned to routes on the MN TH7 corridor. The same sample of ten operators from the field operational test (Rakauskas et al., 2003) was used in the track testing. One driver was removed due to equipment failure just before his test session. One driver did not experience the DAS condition and another did not experience the TRAN condition due to equipment failures. Therefore, the analyses below were based on eight participants (n = 8) unless otherwise noted. The average age of the drivers studied was 39 years (minimum 26, maximum 60 years). On average, these drivers have been working for Mn/DOT or McLeod County for eight years (minimum one, maximum 38 years) and have nine years of plowing experience (minimum one, maximum 36).

Since their training session and during the field operation testing, most drivers have had the opportunity to become more familiar with the system and its functions on their normal plow routes. Two-thirds of the drivers claimed to have used the DAS before the track testing (six out of nine drivers). When asked, "How frequently did you use the DAS during low-visibility conditions," drivers rated an average 44 on a scale from 0 = "never" to 100 = "all of the time." On average, those who used the DAS used it ten times during the winter season (minimum three, maximum 20 times) and the duration of each use was three hours (minimum two, maximum six hours).

The track testing took place on the Minnesota Road Research Project's Low Volume Roadway (Mn/ROAD) outside Otsego, MN. The track is a 2.5 mile long, two-lane loop with one paved access road at the south-eastern end. A simplified diagram of the Mn/ROAD testing track is shown in Figure 2.1. Plow operators drove clockwise around the track starting at the Start/Stop point. A "lap" was completed when they reached the Start/Stop point again. Three laps were considered a "circuit."

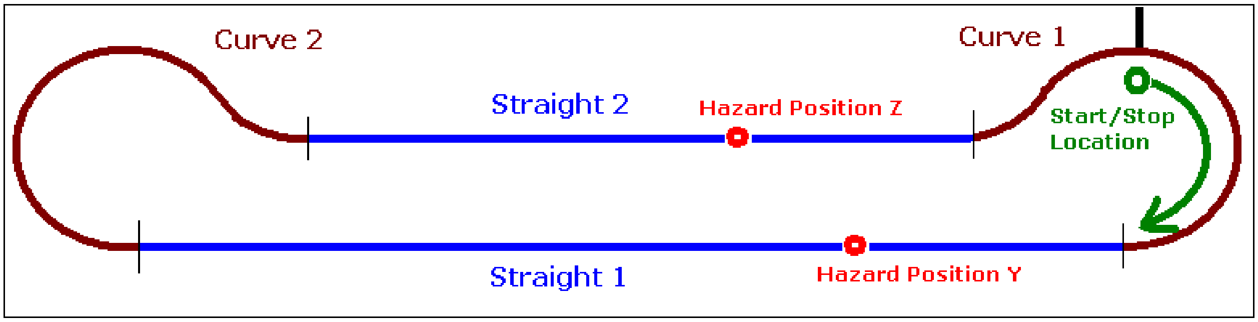


Figure 2.1. Schematic diagram (not to scale) of Mn/ROAD testing track, with demarcated "Start/Stop Location", Straight and Curve labels, and Hazardous Event Positions X & Y

Drivers were asked not to exceed 25 miles per hour while driving on Straight 1. For Straight 2, operators were instructed to drive at a speed that they were most comfortable.

Experimental Design

This study used a "within subjects" design, where operators drove one circuit (three laps) under each of these four conditions:

- **Control (C)** – No visual hindrance by window tint or headlight filters
- **Low Visibility (LV)** – Visibility is hindered by window tint and headlight filters
- **LV DAS (DAS)** – LV condition, with DAS assistance throughout
- **LV 3M Transition (TRAN)** – LV condition, cycling between DAS assistance for 30 seconds and 3M lane detection assistance for 15 seconds

During the field operation test, the 3M lane detection system was used as a backup in enabled areas, in case the DAS lost its GPS signal. In our design, periods of signal loss were simulated in order to test the drivers' reaction to transitioning between the full DAS and the 3M magnetic tape lane detection system.

When GPS goes out it can be due to many reasons. The most common are the loss of the correction signal due to a gap in the RF coverage, the loss of satellite coverage due to foliage or landscape, the transition between coverage towers, and poor satellite geometry. The time to recover a fix from the loss in RF coverage depends upon the size of the RF gap, but usually it is under one minute. The loss of fix associated with the transition between towers is about 15 seconds. The loss of satellites is also usually on the order of deci-seconds. The loss due to poor satellite geometry could be from 15 minutes to a few hours.

The losses due to the landscape (RF coverage, satellite obstruction) and base station transition happen at the same places on the road, so their frequency depends upon the length of the driver's route and the number of times they pass through those particular locations on the road. The poor satellite geometry loss of fix tends to happen at certain times during the day. Therefore, it was suggested that we should present the DAS for 30 seconds and then the 3M tape system for 15 seconds during the TRAN condition.

The 3M tape system was presented as it was in the FOT, this being a numbered line on the HUD. Above the line is a caret that moved across the line to indicate the truck's deviation from lane center on a scale from –3 to 3 feet (therefore 0 was lane center).

Drivers were not expected to perform as well while using this 3M tape system since this implementation is not configured as it was originally intended. Past studies suggest that the optimal configuration for the tape system is only through haptic lateral warnings through the vibrating seat (McGehee and Raby 2002). Though this system was not originally intended for use as a (visual) tracking display, it has been implemented as a continuous view of lane position on the HUD in the DAS. Alternative to audio and seat lateral warnings, peripheral flashing light warnings were recommended.

One difference between the FOT and this track testing was that operators were not given the ability to adjust or turn off any DAS component. This included turning on/off the HUD, haptic seat lateral warning, and audio lateral warning. They were also not allowed to adjust the system's reported offset from center of lane or to adjust the volume of the warning sounds.

The experimental track sessions were conducted from the evening of March 24th through the morning of April 2nd, 2003.

Equipment

Vehicles

The vehicle used was single-axle truck owned, operated, and maintained by Mn/DOT from the Eden Prairie station (Figure 2.2). This truck was used during the FOT from that station, and was equipped with the same Driving Assistive System used in Phases I & II of this project. The truck was configured with a front plow, which was included in order to simulate a real-world plowing configuration and truck weight distribution.

Figure 2.2. The truck equipped with a front plow and the DAS that was used during track testing and (insert) close-up of right headlight blinder while not covering light

A car was also used to follow the truck at all times. The car drove with only its parking lights on at a safe distance behind the test truck. It was the responsibility of this car to signal the truck when to start and end the circuit, to follow the truck in case they strayed from the track, and to be available to the participant should a problem arise.

Obstacles

The obstacles were constructed so that if they were hit, they would fold easily and not damage the truck or endanger the driver. They consisted of construction stanchions with a flat piece of foam attached to them (Figure 2.3).

Figure 2.3. Hazard obstacle; picture taken without and (insert) with flash.

Additional radar-reflective material was attached to the foam so as to better reflect radar from the truck. The obstacle and foam arm were covered with a dark material. One half of a license plate was attached to the center of the foam arm in order to better imitate a small vehicle, such as a trailer.

Loading Task

The in-vehicle loading task was implemented to increase overall workload, given that driving on a test track is intrinsically easier than driving in traffic on the real road. So to make the test track more realistic, we artificially increased workload with the secondary loading task. Otherwise, the conclusions of the evaluation would not be valid under conditions of much lower workload than actual driving. For example, a system that requires effort may result in performance benefits if used on low workload conditions, but might result in worse performance if the system requiring effort is used in an already complicated and effortful environment.

The drivers were to perform the loading task while driving the four circuits. Operators performed the choice Reaction Time task (RT task) using the touch screen. Time and accuracy measures were taken to see if the DAS and 3M systems allow operators the spare mental capacity to complete an additional task accurately while maintaining safe driving behavior. The nature of the choice RT task makes it possible to measure the difficulty that the conditions imposed upon the driver, since the difficulty of the RT task is known.

The RT Task was presented on the touch screen where the DAS interface is normally presented. Drivers were presented with the RT task of pressing a button whenever they heard a tone. The particular button they press was determined by lighting up a circle above the correct button. Figure 2.4a. shows when the task is inactive and Figure 2.4b. shows when the driver must press the button underneath the second circle.

a. b.

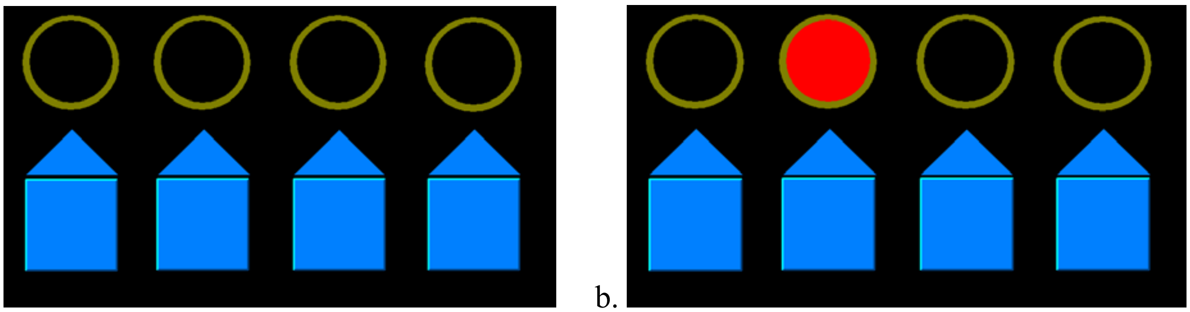


Figure 2.4. Choice Reaction Time Task as shown on the DAS touch screen interface: a.) inactive, and b.) during a timed trial

During the task, one of the four circles was chosen randomly and lit. Note that pressing any button will return the red light to black and start the interval counter for the next trial. The interval time between each individual red light varied from five to ten seconds.

The time from when the light was lit to when the driver hit any button was considered the driver's reaction time (RT) to the task. The driver's accuracy at hitting the correct button was also recorded. If a driver did not respond to the task during the time allotted, that trial was considered an incorrect response. Therefore, the drivers' accuracy scores reflect hitting the correct button as well as responding to the task.

The task was only active along Straights 1 and 2 of the course. The task was active when the plow reached the beginning of Straight 1 and stopped when the plow reached the end of Straight 2 of the third lap (i.e. the end of the circuit).

The results of the loading task are presented in Appendix G. The RT results suggest that drivers were able to respond to the additional loading task at a similar rate whether they were in clear conditions (C), low-visibility conditions (LV), or assisted (DAS & TRAN). However, the percentage correct response results suggest that drivers had more difficulty performing the loading task while in low visibility. This difficulty was more pronounced while concurrently using the DAS, or while using the DAS while it transitioned to the 3M system (TRAN).

Drivers seemed to have the most problems completing the loading task during the TRAN condition, when compared to normal (C) or unassisted low-visibility conditions (LV). It follows that the transitions in the TRAN condition may have made drivers feel uneasy and that it was not safe to complete other in-vehicle tasks (i.e. the loading task).

This suggests that drivers were faced with trading speed for accuracy. By this, we mean that drivers chose to answer quickly whenever they felt it was safe to do so, as evidenced by the similar RT results for all four conditions. When drivers did not feel it was safe to answer quickly, they chose not to answer at all which is evidenced in their percentage of correct responses (their accuracy). Thus, drivers were focused on answering as quickly as possible and in the process sacrificed the accuracy of their responses.

Low-visibility Conditions

Given that the DAS is intended for poor visibility, then we need to evaluate it in a valid condition of poor visibility for the evaluation to be relevant. Thus, it was necessary to simulate poor visibility and then validate this by examining driver response to confirm that our simulation does resemble the types of experience typical for real conditions of poor visibility.

The study was conducted at night, so that there were fewer visual cues to aid the operators during all four conditions. Specifically, testing was conducted after astronomical twilight (the sun was more than 18^{o} below the horizon). During testing, the moon was present only during 1 driver's trials (38% visible), though there was 50% cloud cover as well.

The truck was further equipped with movable headlight blinders (see insert of Figure 2.2) and window-tinting for the LV conditions (LV, DAS, and TRAN conditions). The headlight blinders were made of a shaded Plexiglas and attached to a pivoting base. All exterior lights, aside from the plow front headlights were securely covered while testing. The window-tinting was of the static-cling variety for ease in application and removal between conditions.

Each night of testing we recorded the temperature and weather conditions, measured the brightness of both headlights, and completed a visibility distance task. This was always completed near midnight. The brightness of each headlight was measured with and without the blinder installed using a lux meter. The right headlight produced 125.2 lx with and 301.2 lx without the blinder, which is a 42% reduction in illumination. The left headlight produced 136.4 lx with and 288.6 lx without the blinder, which is a 47% reduction in illumination.

Visibility Distance Measure

The visibility distance measure consisted of placing an object at an undisclosed location on the track and having a plow operator drive the track until he could see the object. For consistency, our trailing car driver was used as the driver for the visibility distance measure on all testing nights. This was first completed with the truck prepared for the control condition, and then the windshield tinting and headlight blinders were set in place and the process was repeated for the LV condition.

The distance from the truck to the object was measured. The difference in distance was considered a reliable measure of visibility decrement. In the control condition, the driver saw the object at an average of 312.91 feet. In the LV condition the driver saw the object at an average of 197.72 feet. This represents a reduction in viewing distance of 37% for our LV conditions (i.e. LV, DAS, and TRAN).

Difficulty Verification

To make sure that our methods of producing low visibility that limited viewing distance, we compared performance and subjective experience between the clear-visibility (C) and unassisted low-visibility (LV) circuits. This comparison allows us to verify that our low-visibility methods (i.e. window-tinting and headlight blinders in the LV condition) hinder the performance of drivers and increase the effort needed to drive safely, as compared to Clear conditions.

Overall mental workload and hazard avoidance results of comparing the C to LV conditions are contained in Table 2.1. The RSME is a single-scale measure of subjective mental workload, ranging from 0 (low mental effort) to 150 (high mental effort), and is explained in detail in the Methods section.

				Wilcoxon Signed Ranks Test		
Performance Measure	Metric	Mean C	Mean LV	Z	*p*	Power
Mental Workload	RSME	18.3	27.3	2.55	0.011 *	0.947
Hazard Avoidance	Distance to Hazard (ft)	371	188	2.38	0.017 *	0.841
	Mean Reaction Time (s)	7.78	4.57	2.24	0.025 *	0.787

* Significant at .05 level

Table 2.1. Wilcoxon Signed Ranks Tests for RSME subjective mental workload and hazard avoidance measures.

Drivers expressed being exposed to significantly more mental workload after the low-visibility driving than after the clear visibility driving. In addition, drivers in the low-visibility condition were significantly slower at seeing the hazard, as seen in their worse distance to hazard and mean reaction time to the hazard target. These results show that not only did drivers think they had a more difficult time in the low-visibility condition (in terms of greater mental effort), but they actually did perform worse than in clear conditions.

The objective driving performance results from Straights 1 and 2 were no different than those of the Curves. Also, only the speed data showed significant differences between the C and LV conditions. For these reasons, the speed data from both Straights and Curves are discussed here though only the results from Straight 1 are presented. The objective driving performance results are presented in Table 2.2.

				Wilcoxon Signed Ranks Test		
Performance Measure	Metric	Mean C	Mean LV	Z	*p*	Power
Speed	Standardized Mean (Z)	1.72	0.57	2.38	0.017 *	0.912
	% Time > 30 mph	38%	25%	0.42	0.674	0.143
	Standard Deviation	2.62	2.99	1.82	0.069 '	0.552

' Marginally Significant
* Significant at .05 level

Table 2.2. Wilcoxon Signed Ranks Tests for speed performance measures during Straight 1.

Drivers drove slower while experiencing low-visibility conditions than they did in clear visibility. This shows that drivers were compensating for higher effort while not being able to see as clearly by driving at slower speeds. Their speed was also slightly more variable while under low-visibility conditions than it was during clear conditions.

Overall, it seems that our low-visibility manipulation was quite effective at lowering drivers' performance by increasing their subjective mental workload. Our artificial low visibility seemed to cause trends in performance that suggest drivers had more difficulty seeing the road during the low-visibility condition than in the clear condition. Higher mental workload, shorter detection distance, and slower speeds found in our artificial condition are consistent with changes expected in actual low-visibility from snow or fog conditions.

PROCEDURE

Since all of the drivers were familiar with the system through the FOT, no specific training on how to use the system was given during the track testing.

Around midnight each night, the temperature was recorded from an in-dash digital thermometer located in one of the researcher's automobiles. The average temperature was 40 degrees F (ranging from 29 F to 44 F). There was no precipitation except for one night when there was a heavy and wet snow.

Instructional Session

After filling out a demographic questionnaire pertaining to plowing experience and employment with Mn/DOT or McLeod County, participants read along as instructions for the track testing were read by the experimenter (Appendix B).

Participants drove five practice laps before driving the experimental laps to get acquainted with the track and the experimental tasks. These laps and instructions took approximately one hour to complete. During the practice laps, the script found in Appendix B was used. The practice laps had the following purposes:

- <u>Laps 1 & 2 – Track Familiarization</u>: Participants were to get used to driving the track at night and keep an eye out for dangerous sections of track. They were shown by the experimenter where rough sections of track were as well as where the equipment boxes were located. This lap was driven under Control visibility conditions.
- <u>Lap 3 – Loading Task</u>: The loading task was explained and shown to the participants before they drove this lap while practicing the task. This lap was driven under Control visibility conditions.
- <u>Lap 4 – Low Visibility</u>: The window tint and headlight blinders were put into place as they would be in the Low-visibility condition and the participant drove a lap to see what it was like to drive under these conditions. Afterward, participants were shown the three workload measures and were asked to fill them out, as described below.
- <u>Lap 5 – DAS – 3M Transition</u>: The 3M Transition (TRAN) condition was turned on and explained to the driver. The participant then drove a lap while experiencing this under Control visibility conditions. This was mean to reacquaint drivers with the DAS display as well as to show them the TRAN condition. Afterward, the participant was asked to complete the workload measures again. Then they were shown the Usability and Trust scales and asked to fill them out. They were then told that during the experimental circuits they would be interviewed after filling out the survey materials.

An obstacle was present on Straight 2 for all practice laps ("Hazardous Position Z" in Figure 2.1), in order to get the participant familiar with the obstacle's appearance in all of the conditions. Participants were told to signal a left turn as soon as they saw the obstacle, so that the experimenters could refer to this time in the recorded data. Drivers were then to avoid the obstacle as if it was a stranded car on the fog line.

Experimental Period

After a short break to set up the plow for the first condition, the experimenter went over some instructions again, listed in the Experimental Circuit Instructions of the script (Appendix B). Drivers were told not to start until given a signal from the trailing car.

Once driving, the participant was to maintain a speed at or below 25 mph on Straight 1 and any speed they felt safe driving (below the speed limit of 35 mph) on Straight 2. Though we recommended these speeds, the participants were told to maintain a speed they felt would allow them to keep the truck under control. They were also reminded of the procedure involved in avoiding the obstacles. It was also emphasized that if they did not feel safe at any time they could stop and notify the experimenters of the problem.

The driver then drove one circuit per condition, taking breaks if needed or to change the visibility condition of the plow. The experimental period took between 2 to 3 hours to complete.

During one lap of the circuit, drivers encountered an obstacle in their path. They were told to avoid hitting the obstacle as if it was a car stranded on the road. It was placed in one of two locations, balancing location with condition so as not to skew the results. When placed in the lane, the obstacle was positioned on the fog line so that the long arm extended out 4 feet into the lane.

After each circuit, the mental workload measures were administered. After the DAS and TRAN circuits, the usability and trust scales were administered as well as an interview pertinent to that condition. After all circuits and measures were completed, the driver was interviewed an additional time and given an end survey (Appendix F).

MEASURES

Data were collected to measure Driving Performance and Subjective Workload for all conditions. Usability and Trust measurements were taken for the DAS and TRAN conditions.

Driving Performance

The driving performance measures we used for the evaluation were related to steering, speed, lane departures, responses to obstacles, and the loading task. These were derived from the engineering data collected by the vehDAQ, and collected at a rate of 10 Hz.

Steering

Steering was continuously sampled throughout each circuit 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 steering measures were collected:

- Standard deviation (variation) of steering wheel position.
- Mean of steering intervals – time intervals between steering wheel “reversals”.

The mean of steering intervals measure is based on published metrics (Verwey & Veltman, 1996) and was measured as the time between successive steering movements. Take for example the steering wheel angle data in Figure 2.5, where steering wheel angles above 0 show times where the center of the wheel is turned to the right, and negative values when the wheel is turned left.

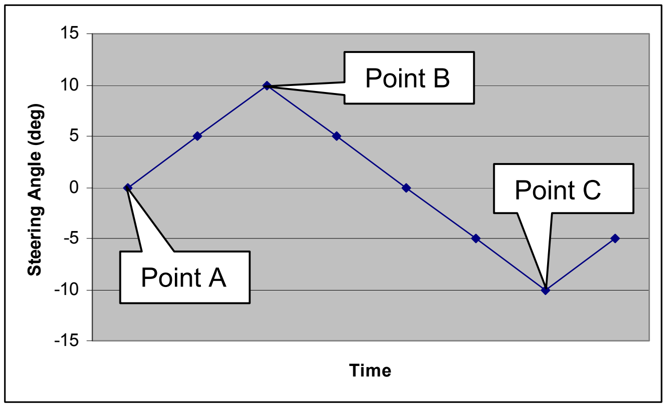


Figure 2.5. Example data to illustrate how steering wheel "reversals" are measured

At 'Point A', the steering wheel begins turning to the right, up until 'Point B'. At 'Point B', the wheel stops its steady rotation to the right, and begins turning to the left. By definition, 'Point B' and 'Point C' are "reversals" since that is when the wheel's angular velocity switches towards the opposite direction. Therefore, in this example, a steering wheel "reversal" is considered to be the period of time between successive inflection points (i.e., the period of time between 'Point B' and 'Point C').

It has been shown in past studies that steering frequency increases when drivers are put under higher levels of mental workload (Verwey & Veltman 1996). We expected drivers having higher variation in their steering as well as more frequent steering "reversals" during periods of low visibility (LV, DAS, and TRAN). Also, we expected the DAS (DAS and TRAN) to aid the drivers and show less variance and less frequent steering intervals than during unassisted (LV).

Speed

Speed was continuously sampled throughout each circuit for each condition. The vehDAQ collected speed directly from the vehicle in Miles Per Hour. The following speed measures were collected:

- Standardized Mean and standard deviation of speed during Straight 1.
- Percent of total time that speed was above 25 mph during Straight 1.
- Mean and standard deviation of speed during Straight 2 and both curves, where drivers were to drive at whatever speed they felt comfortable (below 35 mph).

For Straight 1, the Standardized Mean was calculated as a Z score for each driver on each condition. The equation used to do this was:

$$Z = (\text{Mean Speed} - 25) / \text{Standard Deviation}$$

25 mph was the target speed while driving on Straight 1, therefore 25 was subtracted from the mean speed to determine how far each driver varied from this target speed on average. The

result was then divided by the standard deviation in speed for that condition, producing a standardized (Z) score.

It has been shown in past studies that the more drivers are distracted or the more they have to deal with in their environment, the more they will slow their speed (Brown et al., 1969; Haigney et al., 2000, Waugh et al., 2000). Therefore, we expected drivers to drive slower during periods of low visibility (LV, DAS, and TRAN), and that the DAS (DAS and TRAN) aids the drivers by allowing them to maintain a higher speed than during unassisted (LV).

Lane Position

Lane Position was continuously sampled throughout each circuit 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 lane position 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 lane position measures were collected:

- Mean and standard deviation of lane position.
- Median and maximum (based on the 85th percentile) of inverse Time-to-Line Crossing (1/TLC)

TLC is measured as the distance from outside sidewall of the tire to the nearest lane boundary divided by lateral speed. It is a measure of how long it would take to drive outside of the lane boundary if no changes in steering are made. This is useful in measuring the relative safety of a driver over time.

Note that for presentation and analytic purposes, the TLC data was inverted (1/s) to eliminate logical infinite values that occur when vehicles drive straight near the lane's center. In addition, the maximum values of TLC are typically unrepresentative of the data as a whole. Therefore, the 85^{th} percentile values were used as more "typical" extreme values and the median was used for our analyses.

Lane Departures

Since the primary function of the system is lane support, these measures are the most relevant to overall system performance. Lane Departure measures were sampled in the same manner as the Lane Position measures were. However, these measures deal with the truck when it drove outside sidewall the lane boundaries. A truck was considered to be outside of the lane (i.e. a lane departure) when the outside of the tire crossed over the lane boundary. The following lane departure measures were collected:

- Percent of time spent outside of the lane.
- 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 maximum exceedance time – duration from exit and return point of the tire relative to the lane boundary.

The reader should be reminded that the DAS alerted drivers not only when they actually traversed a lane boundary, but also in instances when they were heading out of the lane boundaries. To explain, the truck's heading was continuously monitored by the system in order to detect when it appeared that the truck was heading outside of the lane and the DAS in turn warned the driver. Therefore, what is being measured in the C and LV conditions is full recovery from outside of the lane boundary. On the other hand, recovery during the DAS and TRAN conditions will have already started before the departure, so there will be less time spent outside of the lane boundaries. Since recovery time is based on time spent outside of the boundaries, the assisted conditions have a distinct advantage over the unassisted conditions.

Hazard Avoidance

Hazard avoidance was tested by placing an obstacle in the path of the plow truck. The DAS can detect objects in its front field of view through the use of radar. Hazard avoidance was calculated based on when the drivers activated their turn signal to signify that they saw the obstacle hazard. The following hazard avoidance measures were collected:

- Distance to the obstacle when it is first seen.
- Reaction time (RT) to seeing the obstacle.

Hazard detection is a fuzzy measure given that it requires the drivers to follow instructions to use their turn signal when they detect a hazard. Depending on compliance with these instructions and variability in reaction times, there will be error in this reported measure. Moreover, the error may bias the two systems; if there is more effort to process the information, then drivers in this condition may adapt a strategy of postponing indication of the target even though it was detected. Even so, these measures were determined to be the safest and most reliable ways to measure reactions to unexpected events in our study.

Subjective Measures

The subjective measures we used for the evaluation are related to mental workload, usability, trust, and the overall objectives of the study. These measures were collected during and after the experiment by giving the drivers surveys and interviews.

Subjective Mental Workload

Drivers were given the Rating Scale of Mental Effort (RSME) after each circuit, so that comparisons could be made between all four track test conditions. The RSME is a univariate scale for rating mental effort (Zijlstra, 1993). It has been shown to be a good measure of mental effort in cases where a secondary task is presented. It was presented on paper as a single continuum with specific points marked with workload descriptions. Operators marked the place on the continuum that best described the level of workload they just put forth. This survey does not allow drivers to provide direct comment about the system itself but on how much effort it took the driver to complete the last circuit under the experimental conditions.

Usability

The operators were asked questions regarding the desirability of these functions during interviews after the DAS and TRAN circuits. Then the operators were given a measure of usability in terms of the drivers' satisfaction with the system and perceived usefulness (as described in Van Der Laan, Heino, De Waard, 1997). The driver completed this series of questions (Appendix C) just after completing the mental workload scale.

Trust

The operators were asked to rate their perceived trust of the system. This System Trust Questionnaire (Appendix D) asked questions related to a driver's opinion of measures such as the reliability and dependability of the system. From these ratings, measures of trust are derived relating to the following categories (as classified in Lee and Moray, 1992):

- Performance – expectation of consistent, stable, desirable performance/behavior of the system
- Process – understanding the underlying qualities that govern behavior of the system
- Purpose – the underlying motives or intent of the system
- Foundation – how the system is related to natural laws and social order

Interviews

Interviews were also used to examine issues pertaining to the usability, acceptance, inherent safety issues, and effectiveness of training. Interviews were conducted after the DAS and TRAN circuits. Interview questions can be found in Appendix E.

Final Survey

Perceived usability, acceptance, system reliability, safety, and acceptance of the system were measured by a self-report survey (Appendix F) completed by drivers after all driving was completed. Though asking 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 compared to see if attitudes about the system improved after using the system during (simulated) weather conditions in which it was intended to be used.

ANALYSIS

As a reminder, this study used a "within subjects" design, where operators drove one circuit (three laps) under each of these four conditions:

- **Control (C)** – No visual hindrance by window tint or headlight filters
- **Low Visibility (LV)** – Visibility is hindered by window tint and headlight filters
- **LV DAS (DAS)** – LV condition, with DAS assistance throughout
- **LV 3M Transition (TRAN)** – LV condition, cycling between DAS assistance for 30 seconds and 3M lane detection assistance for 15 seconds

For the Performance track test data, four comparisons were investigated to assess specific trends of the four experimental conditions. These comparisons are:

- **Effects of LV Condition** – Comparing the C condition to LV condition (results are reported below but also reported and discussed in the Low-visibility Conditions section of the Methods (page 12))
- **System Effects** – Comparing the DAS and TRAN conditions to LV (no system assistance during poor visibility)
- **Baseline Comparisons** – Comparing the DAS and TRAN conditions to C (no system assistance during good visibility)
- **Effects of Transition Condition** – Comparing the DAS condition to TRAN condition

The test track presented drivers with three distinctly different types of road and driving task. During Straight 1, drivers were to maintain a target speed of 25 mph. Straight 2 was similar in length but drivers were told to drive at a speed they felt comfortable under the emphasized 35 mph speed limit. The two curves were approximately mirror images of each other, and drivers were told to drive at whatever speed they felt comfortable and safe.

Drivers were expected to show different driving behaviors depending upon which segment of track they were driving. For this reason, each of these segments was analyzed separately for our driving performance measures. The exception to this is that the TRAN condition was not analyzed for the curves, since the 3M system was disabled while driving the curves.

All cases of statistical significance are reported with the alpha level of significance (p) and Power. Significance testing was performed using the Wilcoxon Signed Ranks Test, unless otherwise noted. Power was calculated using the results from a one-way ANOVA between each set of conditions.

If a comparison was significant, this implies that the cases being compared were different in a meaningful way. Thus, if the Effect of the TRAN Condition is significant, that means that the DAS and TRAN conditions produced different results on a measure of driving performance and therefore we can infer that the two conditions were in fact different.

The Power of the significance tests tell us the probability that there was enough information in our data to be sure of our results. Higher power numbers mean a higher probability of the results being correct, and tell us there is a good chance that our results could be replicated on another group of drivers.

Since the Usability, Trust, and Interview data do not involve all four experimental conditions, they were analyzed only in relation to the DAS and TRAN conditions (i.e. only in regards to Effects of the Transition Condition). Specific explanations of how these data were analyzed are presented below.

Comparison to a Previous Study

Some of these results have been compared to a similar track test of another 3M magnetic tape lateral awareness system (LAS), which was also performed on Mn/ROAD (McGehee and Raby, 2002). Appendix L explores these results in more detail.

The McGehee and Raby developed the LAS. The hardware basis of the LAS was a 3M magnetic tape lane detection system, similar to the one used in the DAS. The researchers started by collecting driver feedback and then used cognitive task analyses to discern what drivers wanted and needed while driving in low-visibility conditions.

The LAS consisted of a haptic seat and peripheral LED lights to convey primary lane departure warnings, and a control unit to provide detailed information on exact lane position. The control unit could also display lane position for the drivers.

The results in Appendix L review the differences in subjective opinions between the LAS and the DAS drivers on similar questions. In addition, the functional differences between the two systems are explored in light of the subjective opinions in order to make design recommendations for future iterations of these designs and other lane assistive systems.

3 RESULTS: TRACK TESTING

RESULTS FRAMEWORK OVERVIEW

Table 3.1 presents an overview of the objective Driving Performance results and Subjective Measures according to the framework objective they pertain to.

	Driving Performance and Subjective Performance Measures	Subjective Measures - DAS & TRAN Interviews	Subjective Measures - Final Interview
Operability		• Remembering how to use the DAS was difficult	
Safety	• Standard deviation of steering wheel position • Mean of interval between steering corrections • Standardized (Z) mean speed (Straight 1) • % of time above target speed (Straight 1) • Mean speed (Straight 2 & Curves) • Standard deviation of speed • Mean & standard deviation of lane position • Median & maximum inverse of time-to-line crossing (1/TLC) • Percentage of time spent outside of the lane • Median & maximum (85th percentile) response time to lane departure • Median & maximum (85th percentile) time spent in lane departure • Distance & reaction time to hazard target	• Using the DAS made me feel safer • The DAS distracted me very much • Using the DAS made me a safer driver. In what ways? • Why did you find it easier/ more difficult to drive while using the DAS? • Would you like to have the DAS permanently installed in your truck? • Why would you/not want the DAS installed in your truck?	• The DAS helped me spend less time looking for obstacles in the roadway • The DAS allowed me to spend more time doing other tasks • Did the system ever prompt you to make a wrong action or an error in judgment? If so, explain what happened • The DAS made me more aware of my lane position • The warnings provided by the DAS enabled me to respond quickly to a lane departure • Compared to driving unassisted, I felt having it enhanced my ability to maintain lane positon while driving on • The 3M system in the HUD was helpful to maintaining lane position • I was able to maintain control during the transitioning between the DAS and tape HUD displays • I felt safe during the transitioning between the DAS and tape HUD displays
Acceptance - Trust	• Trust - performance, process, purpose, & foundation measures	• I felt more comfortable while using the DAS • 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?	

Table 3.1. Overview of questions presented in the Track Testing Results, by framework objective (continued on next page).

	Driving Performance / Subjective Performance Measures	Subjective Measures - DAS & TRAN Interviews	Subjective Measures - Final Interview
Acceptance - Usability	• Mental Workload • Usability - usefulness & satisfaction measures	• Using the DAS while driving took a lot of effort • The DAS was useful in poor visibility • The DAS provided useful information in addition to my traditional visual cues • It was easier for me to drive while using the DAS • I was satisfied with the overall preformance of the DAS • 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?	• I was easily able to understand the HUD display for the DAS/ 3M system • The DAS was intuitive to me • What would be your ideal DAS component configuration? • I liked the HUD display for the DAS/ 3M system • I imagine using the DAS for 12 hours would be annoying. If so, what components would be most annoying • What changes could be made to the HUD to make it better? • The haptic seat was useful in helping me maintain lane position • I considered the haptic seat annoying • What changes could be made to the • The audio warning was useful in helping me maintain lane position • I considered the audio warning annoying • What changes could be made to the audio warning component to make it better • The transition between the DAS and 3M displays was confusing and distracting • Would you prefer the 3M system to warn you through the HUD, seat, audio, or another method? Explain • Would you like any implementation of the 3M backup system installed? Explain
Reliability		• The DAS provided me with reliable information	• The DAS was reliable

Table 3.2. Overview of questions presented in the Track Testing Results, by framework objective (continued from former page).

DRIVING PERFORMANCE

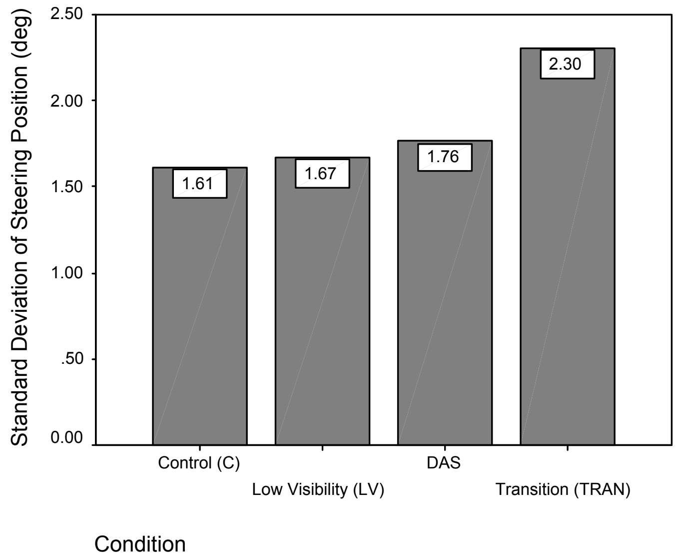
The drivers' objective driving performance on the test track focused on the Safety objective. The results have been organized by the three different sections of the track: Straight 1, Straight 2, and the Curves (see Figure 2.1).

Straight 1 – Target Speed Segment

During Straight 1, drivers were instructed to maintain a maximum target speed of 25 mph.

Steering

Drivers' standard deviation in steering wheel position, while trying to maintain a target speed of 25 mph, is presented in Figure 3.1.



Analysis	Comparisons	Wilcoxon Signed Ranks Test Z	*p*	Power
Effects of LV	C - LV	0.98	0.327	0.087
System Effects	LV - DAS	0.68	0.499	0.085
	LV - TRAN	1.96	0.050 *	0.364
Baseline Comparisons	C - DAS	1.52	0.128	0.254
	C - TRAN	2.24	0.025 *	0.379
Effects of TRAN	DAS - TRAN	1.86	0.063 '	0.268

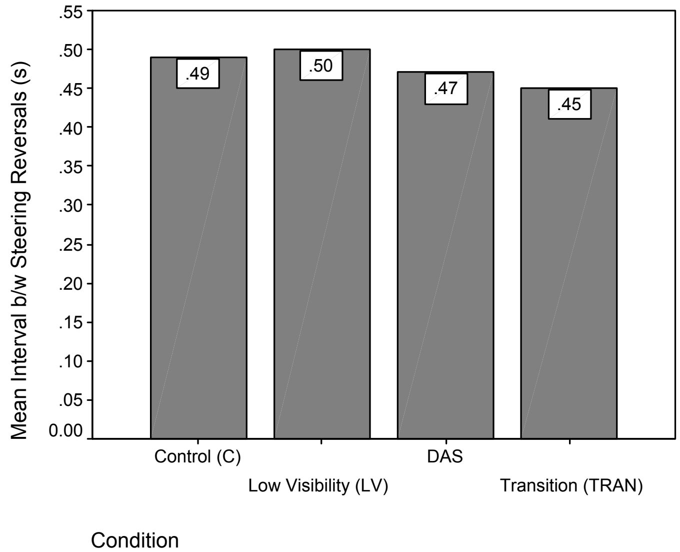
' Marginally Significant
* Significant at .05 level

Figure 3.1. Graph and Wilcoxon Signed Ranks Tests for standard deviation (variability) of steering wheel position on Straight 1

There were significant differences between the TRAN condition and the C and LV conditions, indicating that drivers had increased variability in steering while driving with transitioning assistive technology than during normal low-visibility or clear conditions.

Performance was just as variable during the DAS condition as it was during the C condition. This may indicate that with DAS assistance, drivers maintained as much confidence and control over the vehicle as they did during clear, high-visibility conditions.

The time interval between subsequent steering movements for each condition, while trying to maintain a target speed of 25 mph, is presented in Figure 3.2.



Analysis	Comparisons	Wilcoxon Signed Ranks Test Z	p	Power
Effects of LV	C - LV	0.84	0.401	0.096
System Effects	LV - DAS	2.20	0.028 *	0.865
	LV - TRAN	2.52	0.012 *	0.703
Baseline Comparisons	C - DAS	1.01	0.310	0.169
	C - TRAN	1.26	0.208	0.239
Effects of TRAN	DAS - TRAN	1.01	0.310	0.146

* Significant at .05 level

Figure 3.2. Graph and Wilcoxon Signed Ranks Tests for the mean interval between steering wheel "reversals" on Straight 1

Drivers had significantly shorter intervals between steering responses during the DAS assisted condition (DAS & TRAN) than during the LV condition, as noted in the System Effects. Lower reversal intervals typically indicates that drivers experienced higher levels of mental workload (Verwey & Veltman, 1996), a finding that agrees with the mental workload results discussed in the subjective results below.

This also suggests that drivers were making more frequent steering responses. Since the system provided lane position information, it would be expected that there would be more steering input if the information was utilized. These findings suggest that the drivers were in fact using this information.

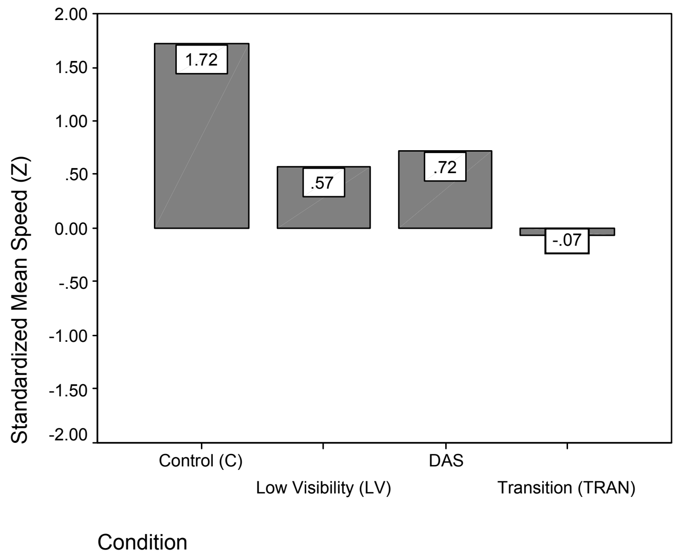
Speed

During Straight 1, drivers were instructed to maintain a maximum target speed of 25 mph. For this reason, special analyses can be performed on the performance measures pertaining to this Straight.

First, to determine whether the drivers maintained the prescribed speed, the standardized scores (based on their mean speed, standard deviation of speed, and the prescribed 25 mph) for each driver on each condition were computed. These scores tell us how far each driver's average speed deviated from 25 mph on that particular condition. We can then compare the standardized scores to see if there are any differences for our comparisons.

We also have looked at the percent of time that the drivers drove above 30 mph, standard deviation of speed, and maximum deceleration as measures of speed variability.

Figure 3.3 shows the standardized speed scores and significance tests for Straight 1. If a driver's mean speed during Straight 1 was 25 mph, their Z score would be 0.0. Thus, scores below 0.0 indicate that the drivers' average speed was below 25 mph and scores above 0.0 indicate that drivers' average speed was above 25 mph.



Analysis	Comparisons	Wilcoxon Signed Ranks Test Z	*p*	Power
Effects of LV	C - LV	2.38	0.017 *	0.912
System Effects	LV - DAS	0.51	0.612	0.076
	LV - TRAN	2.52	0.012 *	0.884
Baseline Comparisons	C - DAS	2.37	0.018 *	0.981
	C - TRAN	2.52	0.012 *	0.998
Effects of TRAN	DAS - TRAN	1.86	0.063 '	0.701

' Marginally Significant
* Significant at .05 level

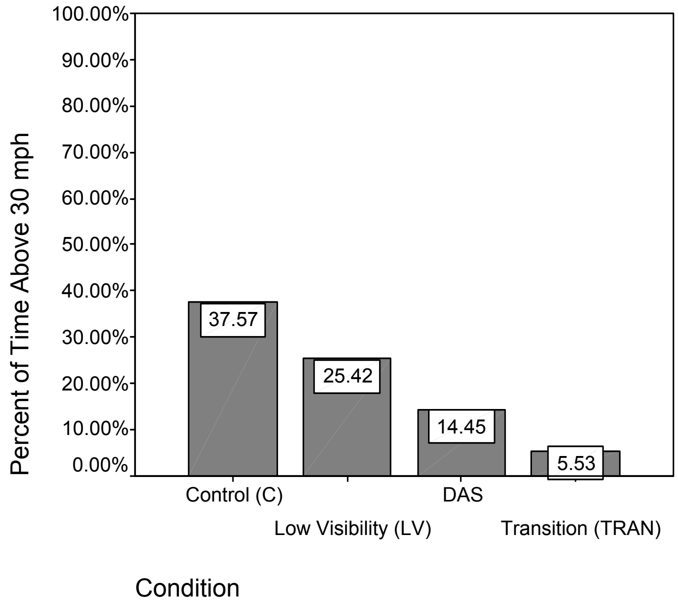
Figure 3.3. Graph and Wilcoxon Signed Ranks Tests for standardized (Z) mean speed on Straight 1

As was expected, drivers in the clear (Control) condition drove significantly faster than drivers in the LV, DAS, and TRAN conditions, as seen in the Effects of LV and Baseline Comparisons. Transitioning between the DAS and 3M systems had the opposite effect of slowing drivers' average speed down below 25 mph, a significant change from the C and LV conditions seen in the Baseline Comparisons to TRAN.

Our results indicate that the speed driven while assisted by the DAS was relatively equal to the speed they felt safe driving at when unassisted (LV). However, having to use both the DAS and

3M systems (TRAN) did significantly slow down drivers. This suggests that the added mental workload of having to switch between the two systems made them drive slower while transitioning in order to feel as safe as they did driving in the DAS condition.

Figure 3.4 shows the percent of time that drivers drove above 30 mph while driving on Straight 1.



Analysis	Comparisons	Wilcoxon Signed Ranks Test Z	p	Power
Effects of LV	C - LV	0.42	0.674	0.143
System Effects	LV - DAS	1.18	0.237	0.102
	LV - TRAN	1.68	0.093 '	0.283
Baseline Comparisons	C - DAS	2.20	0.028 *	0.459
	C - TRAN	1.68	0.093 '	0.421
Effects of TRAN	DAS - TRAN	1.15	0.249	0.161

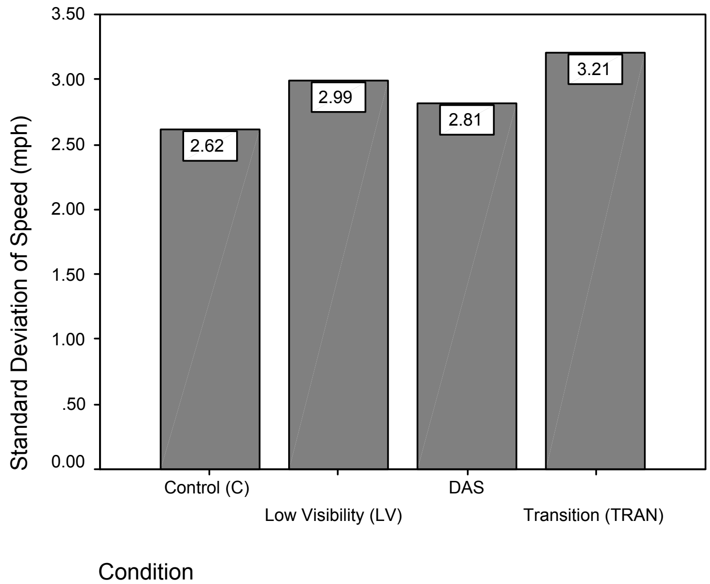
' Marginally Significant
* Significant at .05 level

Figure 3.4. Graph and Wilcoxon Signed Ranks Tests for the percent of time speed exceeded 30 mph on Straight 1.

There was a definite decline in speed instances over 30 mph as visibility decreased (from C to LV) and as assistive systems were included (DAS and TRAN). The DAS Baseline Comparison showed that while driving in low visibility and being assisted by the system, drivers' speed was significantly slower than while driving in clear conditions. This decrease in speed seems to help drivers compensate for having to process the additional information presented by the DAS.

The marginally significant trends suggest that while driving the TRAN condition, drivers spent less time above 30 mph than while driving either the C or LV conditions. It would be of interest to explore these comparisons with a more powerful design due to the small sample size and high variance in the test environment.

The variation in the drivers' speed during Straight 1 can be seen in the standard deviations shown in Figure 3.5.



Analysis	Comparisons	Wilcoxon Signed Ranks Test Z	p	Power
Effects of LV	C - LV	1.82	0.069 '	0.552
System Effects	LV - DAS	0.51	0.612	0.096
	LV - TRAN	0.98	0.327	0.136
Baseline Comparisons	C - DAS	0.68	0.499	0.099
	C - TRAN	1.82	0.069 '	0.472
Effects of TRAN	DAS - TRAN	1.35	0.176	0.325

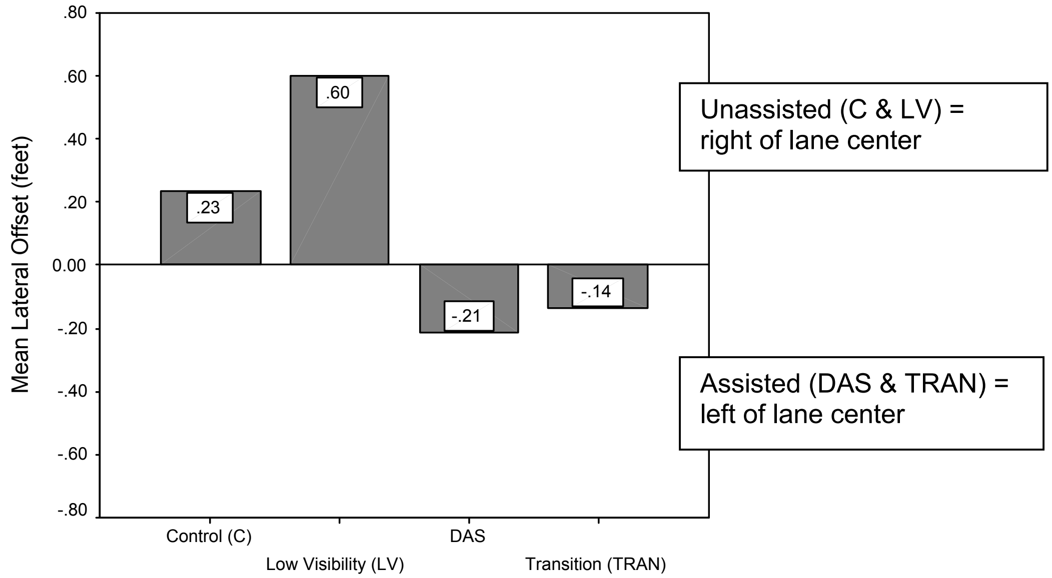
' Marginally Significant

Figure 3.5. Graph and Wilcoxon Signed Ranks Tests for standard deviation (variability) of speed on Straight 1

We would expect to see higher levels of variability in drivers that have more to attend to while driving. This almost seems to be the case as the general trend of the graph suggests, but this is only marginally supported in our statistical test results. Due to the small sample size and high variance in the test environment, it would be of interest to explore these comparisons with a more powerful design.

Lane Position

Figure 3.6 presents the mean lane position during Straight 1, while instructed to maintain a target speed of 25 mph.

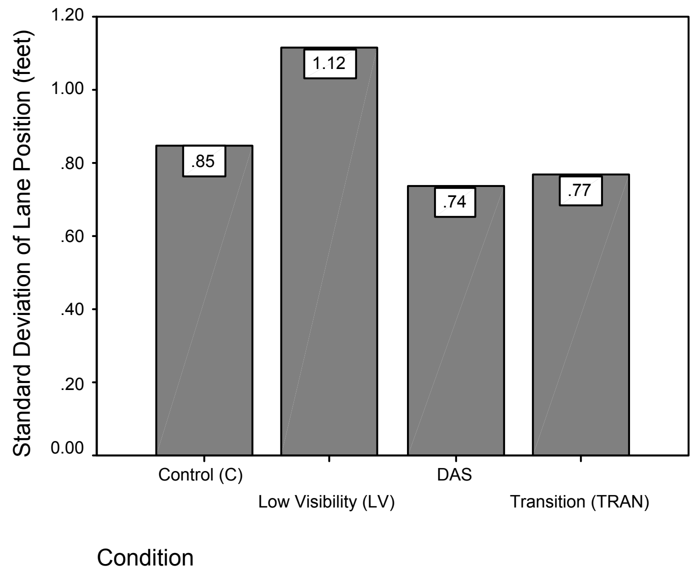


Analysis	Comparisons	Wilcoxon Signed Ranks Test Z	*p*	Power
Effects of LV	C - LV	1.21	0.225	0.136
System Effects	LV - DAS	1.21	0.225	0.248
	LV - TRAN	0.67	0.500	0.164
Baseline Comparisons	C - DAS	1.48	0.138	0.238
	C - TRAN	0.94	0.345	0.137
Effects of TRAN	DAS - TRAN	0.41	0.686	0.068

Figure 3.6. Graph and Wilcoxon Signed Ranks Tests for mean lane position on Straight 1

There were no statistical differences between any of the conditions for lane position. This indicates that over the four conditions, the drivers average lane position remained similar.

Drivers were also consistent in the variation (standard deviation) of their lane position, as seen in Figure 3.7.



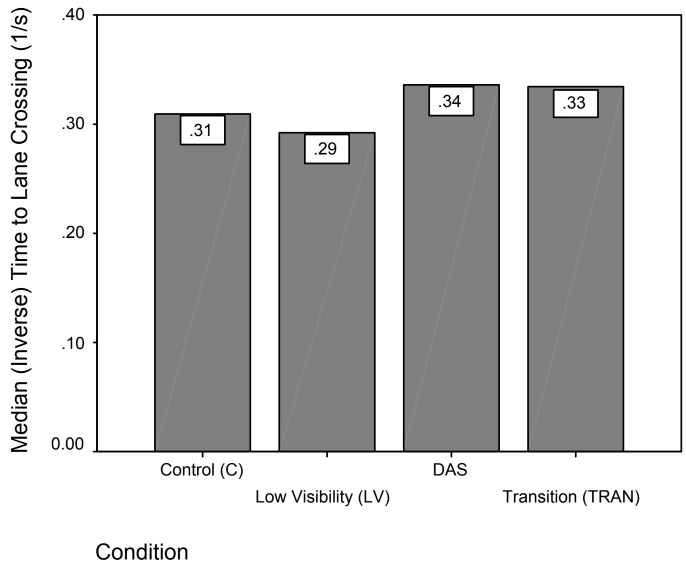
		Wilcoxon Signed Ranks Test		
Analysis	Comparisons	Z	*p*	Power
Effects of LV	C - LV	0.94	0.345	0.085
System Effects	LV - DAS	0.67	0.500	0.158
	LV - TRAN	0.67	0.500	0.134
Baseline Comparisons	C - DAS	0.67	0.500	0.081
	C - TRAN	0.67	0.500	0.062
Effects of TRAN	DAS - TRAN	0.67	0.500	0.097

Figure 3.7. Graph and Wilcoxon Signed Ranks Tests for standard deviation (variation) of lane position on Straight 1

Since their mean and standard deviation of lane position were similar for all conditions, it appears that when drivers were told to maintain a target speed they may have paid more attention to the location of the truck in the lane. In fact, there may have been a trade off in the location of their attention, as drivers drove more slowly in the more mentally taxing conditions but their average and variation in lane position did not differ.

Furthermore, Figure 3.8 presents the median inverse of time-to-line crossing (1/TLC) during Straight 1. One driver's data (Driver R27-8) was excluded from the 1/TLC analyses on Straight 1. The driver experienced wet snow during some of the test track circuits, which may have been why his 1/TLC values for Straight 1 were unduly high.

For presentation and analytic purposes, the TLC data was inverted (1/s) to eliminate logical infinite values that occur when vehicles drive straight near the lane's center. In addition, the maximum values of TLC are typically unrepresentative of the data as a whole. Therefore, the median values were considered more "typical" results for our analyses.



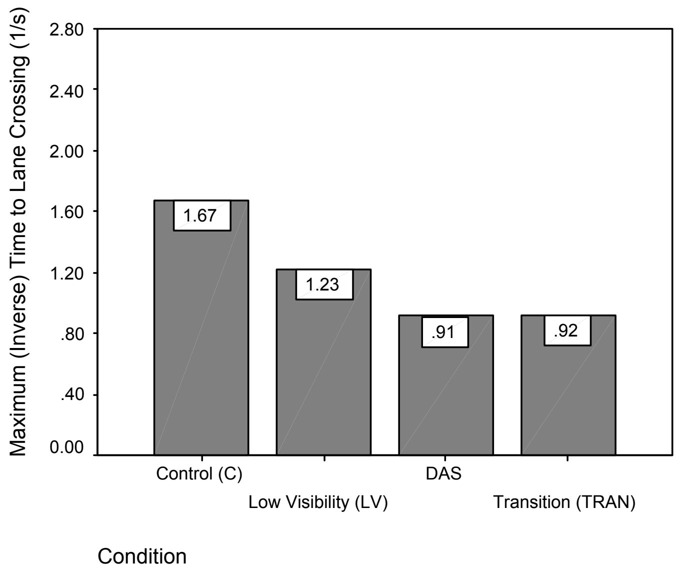
		Wilcoxon Signed Ranks Test		
Analysis	Comparisons	Z	*p*	Power
Effects of LV	C - LV	0.37	0.715	0.058
System Effects	LV - DAS	0.73	0.465	0.133
	LV - TRAN	0.73	0.465	0.097
Baseline Comparisons	C - DAS	1.83	0.068 '	0.328
	C - TRAN	1.10	0.273	0.194
Effects of TRAN	DAS - TRAN	0.37	0.715	0.050

' Marginally Significant

Figure 3.8. Graph and Wilcoxon Signed Ranks Tests for median inverse of time-to-line crossing (1/TLC) on Straight 1 (excluding lane departures)

Based on the inverse of TLC, larger values represent a shorter time-based safety margin. The results are then inverted and described in more conventional terms, such that smaller 1/TLCs indicate safer driving performance. Once again there was no significant difference between any of the experimental conditions.

Figure 3.9 gives us a good impression of what the drivers' most extreme lane position was. The maximum values of TLC are typically unrepresentative of the data as a whole. Therefore, the 85^{th} percentile values were used as more "typical" extreme values for our analyses.



		Wilcoxon Signed Ranks Test		
Analysis	Comparisons	Z	*p*	Power
Effects of LV	C - LV	0.00	1.000	0.059
System Effects	LV - DAS	0.00	1.000	0.067
	LV - TRAN	0.00	1.000	0.066
Baseline Comparisons	C - DAS	0.73	0.465	0.103
	C - TRAN	0.37	0.715	0.097
Effects of TRAN	DAS - TRAN	0.00	1.000	0.051

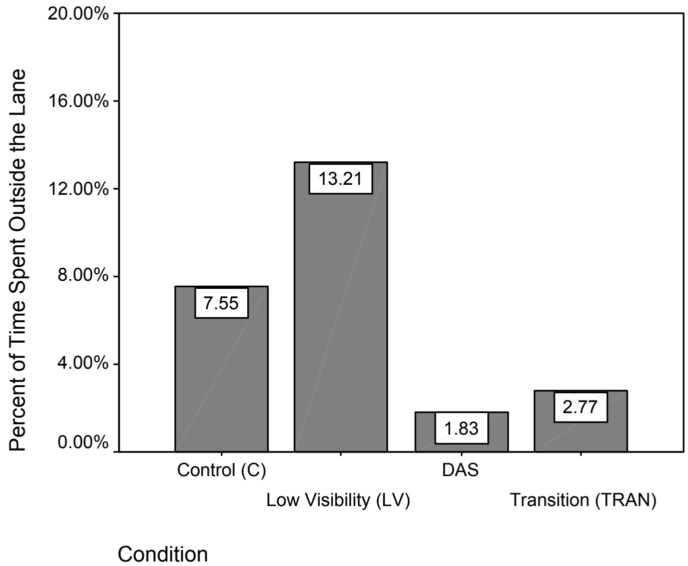
Figure 3.9. Graph and Wilcoxon Signed Ranks Tests for maximum inverse of time-to-line crossing (1/TLC) on Straight 1 (excluding lane departures)

Here again there were no significant differences between the experimental conditions. This adds more proof to our hypothesis that drivers might have been focusing more on their lane position than on their speed while driving.

Though the trend in this data is quite promising, none of the comparisons were significant. Due to the small sample size and high variance in the test environment, it would be of interest to explore these comparisons with a more powerful design.

Lane Departures

The percentage of time spent outside the lane boundaries on Straight 1, while asked to maintain a speed at or around 25 mph, is presented in Figure 3.10.

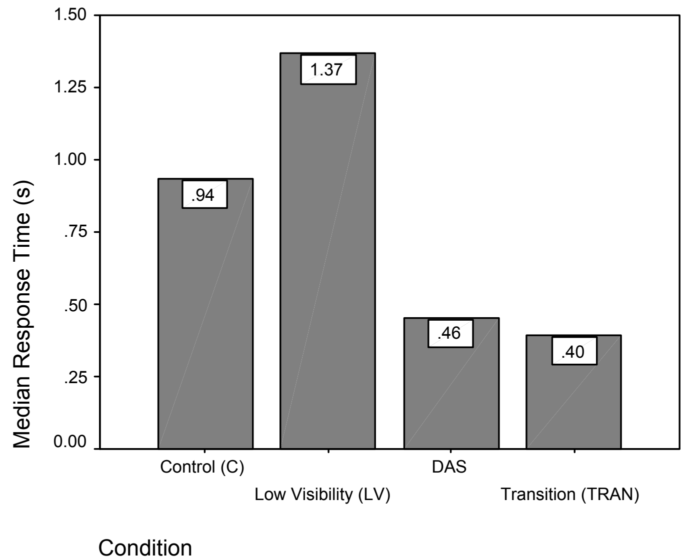


		Wilcoxon Signed Ranks Test		
Analysis	Comparisons	Z	*p*	Power
Effects of LV	C - LV	0.94	0.345	0.088
System Effects	LV - DAS	1.48	0.138	0.162
	LV - TRAN	1.21	0.225	0.138
Baseline Comparisons	C - DAS	1.21	0.225	0.360
	C - TRAN	1.21	0.225	0.250
Effects of TRAN	DAS - TRAN	1.48	0.138	0.304

Figure 3.10. Graph and Wilcoxon Signed Ranks Tests for the percentage of time spent outside of the lane on Straight 1

There were no differences between the conditions for the percentage of time spent outside of the lane. From this data it may be speculated that there is less time spent outside of the lane during the assisted conditions (DAS and TRAN) than the C and LV conditions. Due to the small sample size and high variance in the test environment, it would be of interest to explore these comparisons with a more powerful design.

The median amount of time it took drivers to recover from lane departures is presented in Figure 3.11.

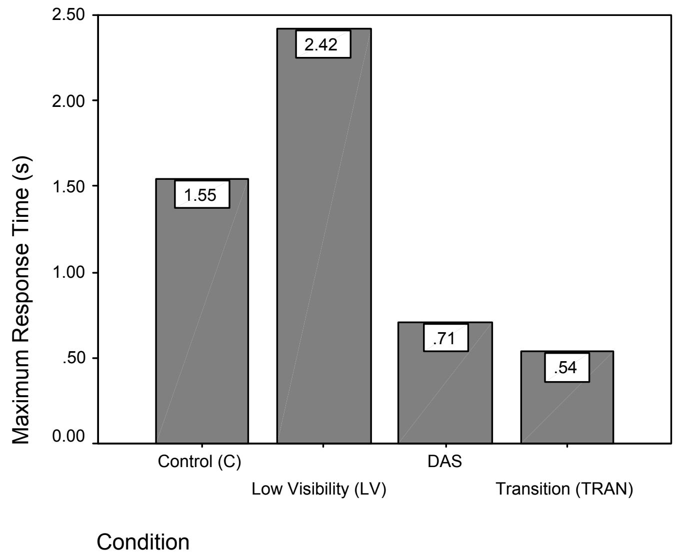


Analysis	Comparisons	Wilcoxon Signed Ranks Test Z	*p*	Power
Effects of LV	C - LV	0.94	0.345	0.074
System Effects	LV - DAS	1.21	0.225	0.183
	LV - TRAN	0.94	0.345	0.143
Baseline Comparisons	C - DAS	1.22	0.223	0.251
	C - TRAN	1.21	0.225	0.187
Effects of TRAN	DAS - TRAN	0.14	0.893	0.054

Figure 3.11. Graph and Wilcoxon Signed Ranks Tests for median response time to recover from a lane boundary departure on Straight 1

There were no differences between any of the conditions for the median response time. From this data it may be speculated that drivers in the DAS and TRAN conditions are able to respond more quickly to lane departures than when they are unassisted (C and LV). Due to the small sample size and high variance in the test environment, it would be of interest to explore these comparisons with a more powerful design.

The maximum amount of time it took drivers to recover from lane departures is presented in Figure 3.12.

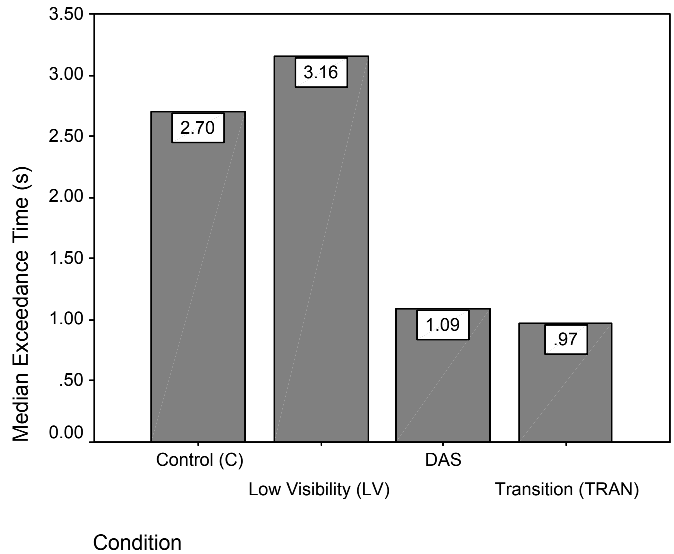


Analysis	Comparisons	Wilcoxon Signed Ranks Test Z	*p*	Power
Effects of LV	C - LV	0.94	0.345	0.098
System Effects	LV - DAS	1.21	0.225	0.256
	LV - TRAN	1.21	0.225	0.196
Baseline Comparisons	C - DAS	1.22	0.223	0.295
	C - TRAN	1.21	0.225	0.228
Effects of TRAN	DAS - TRAN	0.14	0.893	0.069

Figure 3.12. Graph and Wilcoxon Signed Ranks Tests for maximum response time to recover from a lane boundary departure on Straight 1

There were no significant differences between any of the conditions for the median response time. It may be speculated from this data that drivers can recover completely from lane departures more quickly while using the DAS or transitioning DAS (TRAN) than when unassisted (C and LV). Due to the small sample size and high variance in the test environment, it would be of interest to explore these comparisons with a more powerful design.

The median duration of lane departures is presented in Figure 3.13.

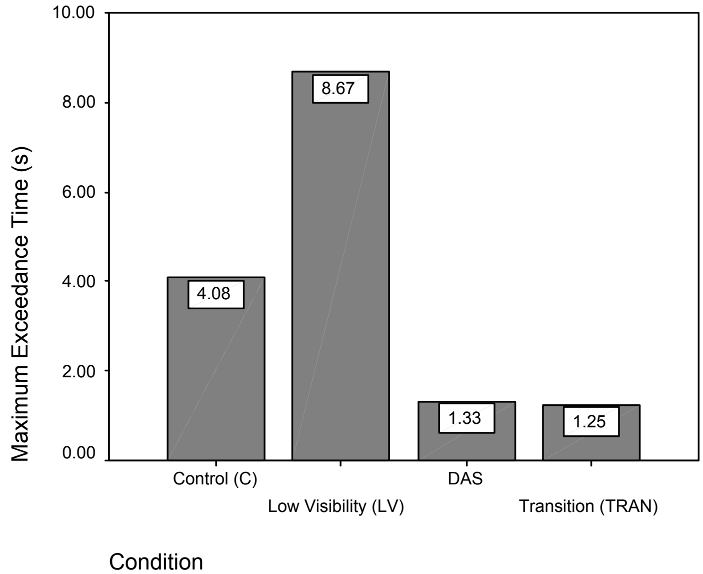


		Wilcoxon Signed Ranks Test		
Analysis	Comparisons	Z	*p*	Power
Effects of LV	C - LV	0.14	0.893	0.057
System Effects	LV - DAS	1.48	0.138	0.274
	LV - TRAN	1.21	0.225	0.203
Baseline Comparisons	C - DAS	1.21	0.225	0.347
	C - TRAN	1.21	0.225	0.207
Effects of TRAN	DAS - TRAN	0.14	0.893	0.054

Figure 3.13. Graph and Wilcoxon Signed Ranks Tests for median time duration of lane boundary departures on Straight 1

There were no significant differences between any of the conditions for the median duration of boundary departures. But once again it may be speculated that assisted drivers (DAS & TRAN) were able to regain the lane more quickly than unassisted drivers (C & LV). Due to the small sample size and high variance in the test environment, it would be of interest to explore these comparisons with a more powerful design.

The maximum duration of lane departures is presented in Figure 3.14.



Analysis	Comparisons	Wilcoxon Signed Ranks Test Z	p	Power
Effects of LV	C - LV	1.21	0.225	0.143
System Effects	LV - DAS	1.48	0.138	0.219
	LV - TRAN	1.21	0.225	0.199
Baseline Comparisons	C - DAS	1.21	0.225	0.370
	C - TRAN	1.21	0.225	0.240
Effects of TRAN	DAS - TRAN	0.14	0.893	0.052

Figure 3.14. Graph and Wilcoxon Signed Ranks Tests for maximum time duration of lane boundary departures on Straight 1

There were no differences between any of the conditions for the maximum duration of boundary departures. It may be speculated that assisted drivers (DAS and TRAN) were able to recover from departures more quickly than unassisted drivers (C and LV). Due to the small sample size and high variance in the test environment, it would be of interest to explore these comparisons with a more powerful design.

Straight 1 – Target Speed Segment Summary

Drivers were to maintain a speed of 25 mph as best they could during Straight 1. Though drivers drove faster than this speed in all of the conditions, driver's exceedance of this limit was based upon the amount of information that they had to process. For example, they drove the fastest in the clear condition, somewhat slower in low-visibility condition, and progressively slower in the DAS and transitioning conditions. Slowing like this is common when drivers have to process more information or when they encounter more complex driving environments.

Driving in low-visibility conditions while assisted by the DAS did not increase the variability of drivers' steering wheel movements, though when drivers were faced with a transitioning system their variability rose. Drivers also made more frequent steering corrections while using both the DAS and transitioning DAS. These speed and steering findings agree with the mental workload findings, that subjective mental workload of the condition rose as average speeds fell (see Subjective Mental Workload, pg 61).

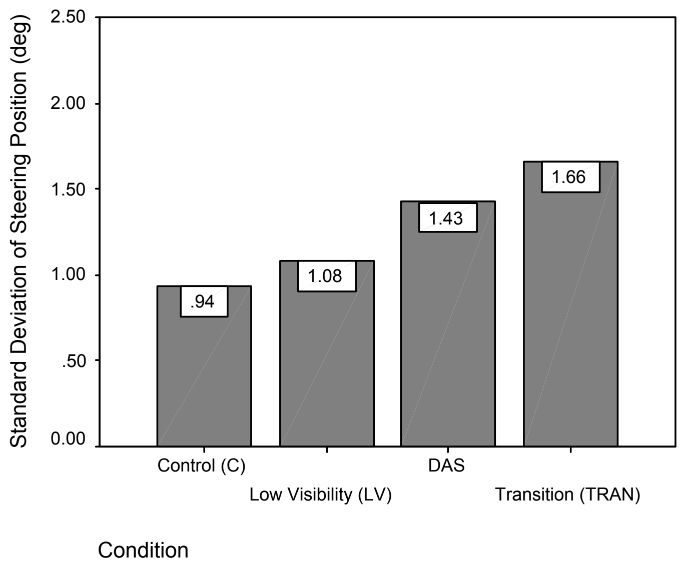
The focus of drivers was to maintain their lane position more than any other factor. This is evident as there were no major differences between the conditions for the lane position or lane departure measures. In essence, drivers were putting more effort into steering to maintain their lane position, at the expense of slower speeds and dealing with more mental workload.

Straight 2 – Comfort Speed Segment

During Straight 2, drivers were instructed to drive at any speed that they felt comfortable (under the emphasized 35 mph speed limit).

Steering

Drivers' standard deviation in steering wheel position, when told to maintain a speed at which they felt comfortable driving, is presented in Figure 3.15.



		Wilcoxon Signed Ranks Test		
Analysis	Comparisons	Z	*p*	Power
Effects of LV	C - LV	1.26	0.208	0.198
System Effects	LV - DAS	1.86	0.063 '	0.448
	LV - TRAN	1.82	0.069 '	0.360
Baseline Comparisons	C - DAS	2.37	0.018 *	0.990
	C - TRAN	2.52	0.012 *	0.532
Effects of TRAN	DAS - TRAN	0.17	0.866	0.092

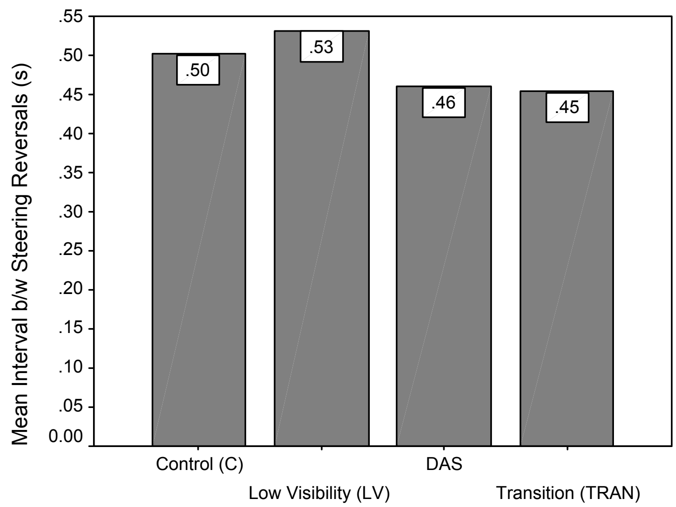
' Marginally Significant
* Significant at .05 level

Figure 3.15. Graph and Wilcoxon Signed Ranks Tests for standard deviation (variability) of steering wheel position on Straight 2

There are strong differences between both the DAS and TRAN conditions and the C condition, indicating that drivers had increased variability in steering while driving with the assistive technology than during clear conditions. This suggests that drivers were making more frequent steering responses. Since the system provided lane position information, it would be expected that there would be more steering input if the information was utilized. These findings suggest that the drivers were in fact using this information.

There were slight differences between steering variability of the assistive technology conditions (DAS and TRAN) and the LV condition, and it would be of interest to explore these comparisons in the future with a more powerful design.

The interval between subsequent steering movements for each condition, while driving at a speed they felt comfortable, is presented in Figure 3.16.



Analysis	Comparisons	Wilcoxon Signed Ranks Test Z	p	Power
Effects of LV	C - LV	1.40	1.610	0.239
System Effects	LV - DAS	2.37	0.018 *	0.981
	LV - TRAN	2.52	0.012 *	0.975
Baseline Comparisons	C - DAS	1.86	0.063 '	0.478
	C - TRAN	1.96	0.050 *	0.669
Effects of TRAN	DAS - TRAN	0.34	0.735	0.059

' Marginally Significant
* Significant at .05 level

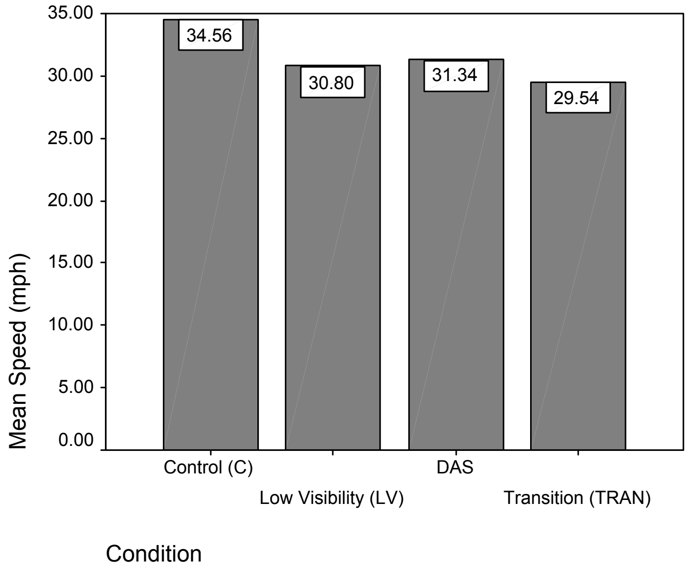
Figure 3.16. Graph and Wilcoxon Signed Ranks Tests for the intervals between steering wheel "reversals" on Straight 2

Drivers had significantly shorter intervals between steering responses during the DAS assisted conditions (DAS & TRAN) than during the LV condition, as noted in the System Effects and as also seen during Straight 1. They also showed shorter "reversal" intervals in the assisted conditions (DAS & TRAN) than in the C condition, as seen in the Baseline Comparisons. Again, this indicates that drivers were under higher levels of mental workload, which agrees with the mental workload results (see pg. 53).

Speed

We analyzed the drivers' average speed to show how comfortable drivers were during each condition, and analyzed their standard deviation in speed as a measure of their speed variability.

Figure 3.17 shows the average speed of drivers in all four conditions.



		Wilcoxon Signed Ranks Test		
Analysis	Comparisons	Z	*p*	Power
Effects of LV	C - LV	2.38	0.017 *	0.897
System Effects	LV - DAS	0.51	0.612	0.091
	LV - TRAN	1.26	0.208	0.266
Baseline Comparisons	C - DAS	2.20	0.028 *	0.948
	C - TRAN	2.52	0.012 *	0.977
Effects of TRAN	DAS - TRAN	1.35	0.176	0.411

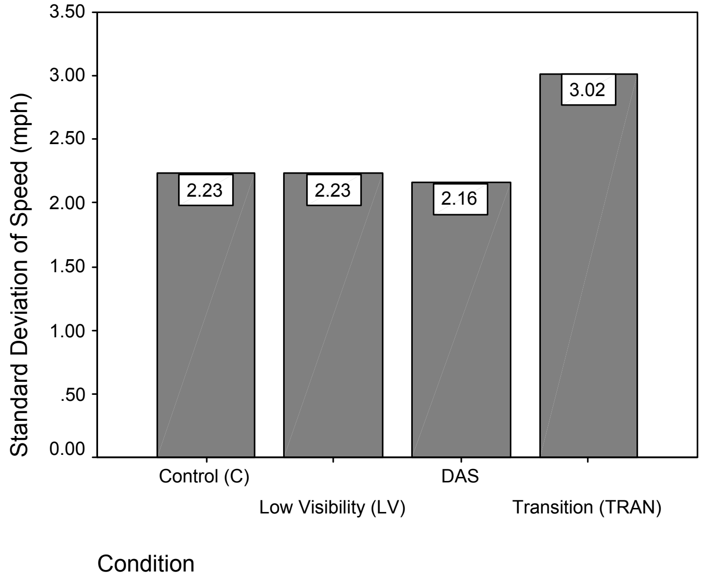
* Significant at .05 level

Figure 3.17. Graph and Wilcoxon Signed Ranks Tests for mean speed on Straight 2

Drivers seemed to drive at or around the speed limit during clear (C) conditions, but dropped down to around 30 mph for both assisted low-visibility conditions (DAS, and TRAN) as seen in the Baseline Comparison analyses. This suggests that while having the assistance of the DAS or when transitioning to the 3M system, the speed at which drivers felt safe was comparable to when driving the unassisted low-visibility condition.

The DAS and TRAN conditions also did not produce an increase in speed, based on the risk compensation assumption. In other words, drivers did not necessarily feel so secure with the system that they could drive faster and consume their safety benefit in order to increase their mobility and plowing performance.

Figure 3.18 depicts standard deviation, or variability, in driving speed where higher levels of variability are related to less control of the vehicle and are therefore considered to be a sign of poor driving performance.



Analysis	Comparisons	Wilcoxon Signed Ranks Test Z	p	Power
Effects of LV	C - LV	0.56	0.575	0.085
System Effects	LV - DAS	0.51	0.612	0.075
	LV - TRAN	2.24	0.025 *	0.665
Baseline Comparisons	C - DAS	0.85	0.398	0.071
	C - TRAN	1.26	0.208	0.300
Effects of TRAN	DAS - TRAN	1.86	0.063 '	0.404

' Marginally Significant
* Significant at .05 level

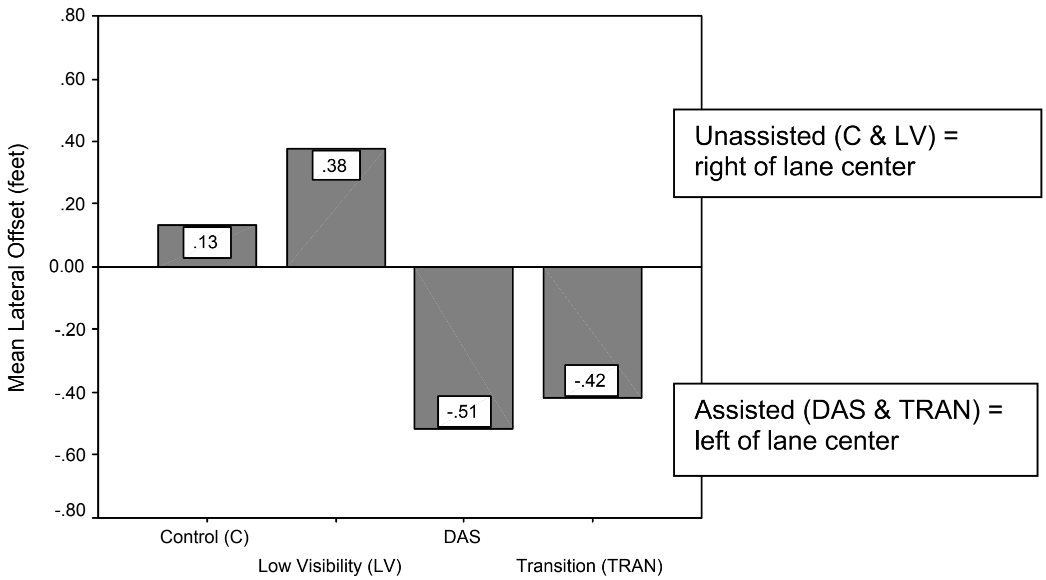
Figure 3.18. Graph and Wilcoxon Signed Ranks Tests for standard deviation (variability) of speed on Straight 2

Here, a different trend can be seen than in the mean speed. Our data show that while driving in the TRAN condition, drivers had a higher level of variability than while driving in the LV condition. The marginally significant Effects of TRAN also suggest that it was more difficult to maintain a constant speed during the TRAN condition than while assisted by a stable DAS. However, this is speculative due to the small sample size and high variance in the test environment. It would be of interest to explore these comparisons with a more powerful design.

Overall it seems that the TRAN condition induced more variability in speed due to (1) distraction during the shift from DAS to 3M interface, and due to (2) the shift from a predictive to non-predictive system that does not support anticipatory speed changes, and hence, only permits fast reflexive speed changes based on immediate information. That is, the DAS interface allows drivers to predict the need for speed change by showing a preview of the road ahead. With this prediction, speed changes can be better controlled leading to smoother and less rapid changes. In contrast, there is no preview with the 3M interface and speed is more variable because it is more ballistic.

Lane Position

Figure 3.19 presents the mean lane position during Straight 2, while drivers were instructed to maintain a speed at which they felt comfortable.



Analysis	Comparisons	Wilcoxon Signed Ranks Test Z	*p*	Power
Effects of LV	C - LV	0.67	0.500	0.111
System Effects	LV - DAS	2.02	0.043 *	0.558
	LV - TRAN	2.02	0.043 *	0.371
Baseline Comparisons	C - DAS	2.02	0.043 *	0.686
	C - TRAN	2.02	0.043 *	0.538
Effects of TRAN	DAS - TRAN	1.21	0.225	0.164

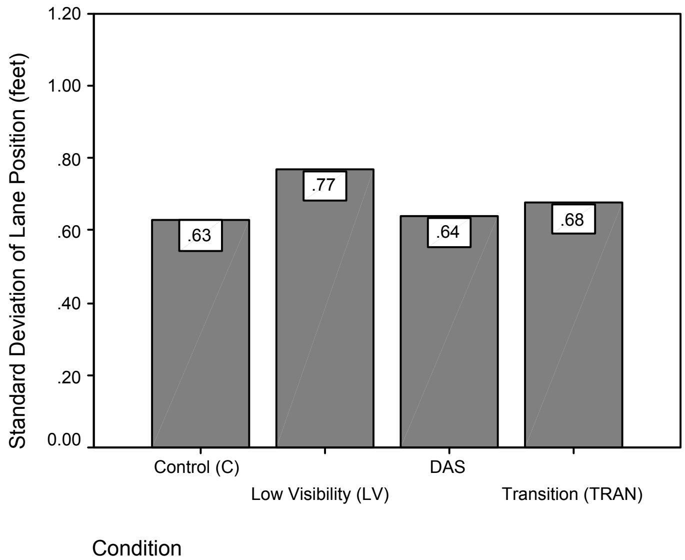
* Significant at .05 level

Figure 3.19. Graph and Wilcoxon Signed Ranks Tests for mean lane position on Straight 2

Unlike Straight 1, in Straight 2 both Baseline Comparisons and both System Effects were significant. In both cases, the median lane position of the drivers while not assisted by the systems (C and LV conditions) was to the right of the lane center. Also, the median position of drivers while assisted by the systems (DAS and TRAN conditions) was to the left of lane center. This effect was could have been due to a difference between how drivers saw the lane in the HUD, or to the GPS system computing the lane center to the left of where it truly was.

On the other hand, this shift in lane position may also have been due to perceptual bias created by the combiner or driver position in the cab. Alternatively, it may have been a strategic response to drivers from increased information about lane boundaries to avoid the high-risk of the shoulder in the absence of approaching lane traffic. Since moving left posed a lower risk, the effect may be more pronounced than it would be in real road conditions.

Measures of standard deviation will show if the effects of low visibility and the systems affected driving performance, regardless of where drivers though the lane center was. These results are presented in Figure 3.20.



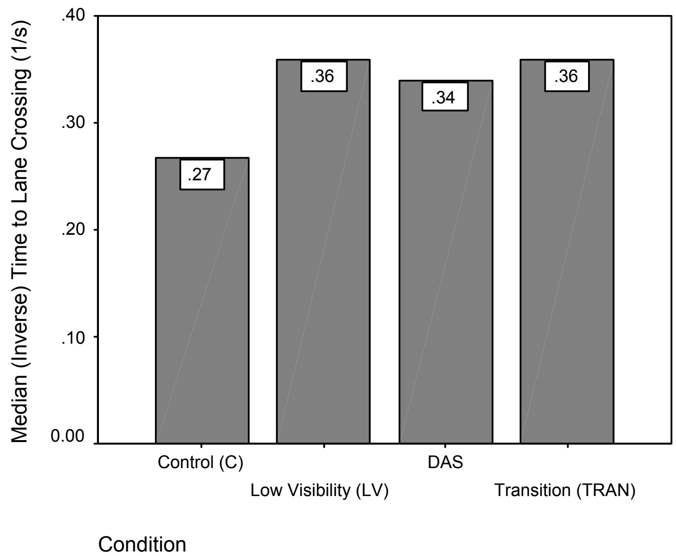
		Wilcoxon Signed Ranks Test		
Analysis	Comparisons	Z	*p*	Power
Effects of LV	C - LV	0.94	0.345	0.144
System Effects	LV - DAS	0.94	0.345	0.160
	LV - TRAN	0.94	0.345	0.088
Baseline Comparisons	C - DAS	0.14	0.893	0.051
	C - TRAN	0.14	0.893	0.063
Effects of TRAN	DAS - TRAN	1.21	0.225	0.149

Figure 3.20. Graph and Wilcoxon Signed Ranks Tests for standard deviation (variation) of lane position on Straight 2

As in Straight 1, there were no significant differences for any of the comparisons on the variation (standard deviation) of their lane position while driving at a comfortable speed.

Since both their mean and standard deviation of lane position were similar for all conditions, it seems that regardless of what speed drivers were told to maintain, they seemed to pay more attention to the location of the truck in the lane. In fact, there may have been a performance tradeoff, as drivers drove more slowly in the more mentally taxing conditions but their lane position did not significantly differ by condition.

Figure 3.21 presents the median inverse of time-to-line crossing (1/TLC) during Straight 2. Again, based on the inverse of TLC, larger values represent a shorter time-based safety margin.



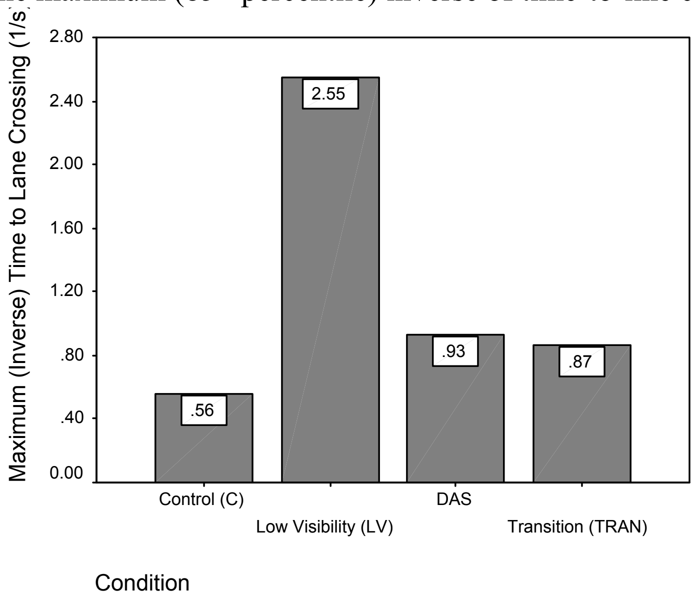
		Wilcoxon Signed Ranks Test		
Analysis	Comparisons	Z	*p*	Power
Effects of LV	C - LV	0.14	0.893	0.109
System Effects	LV - DAS	0.41	0.686	0.052
	LV - TRAN	0.41	0.686	0.050
Baseline Comparisons	C - DAS	1.75	0.080 '	0.396
	C - TRAN	1.75	0.080 '	0.579
Effects of TRAN	DAS - TRAN	0.41	0.686	0.073

' Marginally Significant

Figure 3.21. Graph and Wilcoxon Signed Ranks Tests for median inverse of time-to-line crossing (1/TLC) on Straight 2 (excluding lane departures)

When drivers were allowed to drive at any comfortable speed, only marginal differences were seen for the Baseline Comparisons. Driving while using the DAS and while transitioning between assistive systems caused somewhat higher 1/TLC than driving in clear conditions. Due to the small sample size and high variance in the test environment, it would be of interest to explore these comparisons with a more powerful design.

Figure 3.22 presents the maximum (85th percentile) inverse of time-to-line crossing results.



Analysis	Comparisons	Wilcoxon Signed Ranks Test Z	p	Power
Effects of LV	C - LV	0.67	0.500	0.126
System Effects	LV - DAS	0.14	0.893	0.100
	LV - TRAN	0.14	0.893	0.104
Baseline Comparisons	C - DAS	1.75	0.080 '	0.529
	C - TRAN	1.75	0.080 '	0.322
Effects of TRAN	DAS - TRAN	1.21	0.225	0.177

' Marginally Significant

Figure 3.22. Graph and Wilcoxon Signed Ranks Tests for maximum inverse of time-to-line crossing (1/TLC) on Straight 2 (excluding lane departures)

Similar to when drivers were instructed to drive at a target speed, when told to drive at a comfortable speed there were no significant differences between the experimental conditions. This agrees with the mean 1/TLC results. Though not supported by the Wilcoxon tests, the graph seems to show that the DAS and TRAN (and C) conditions had shorter maximum inverse time to line crossing. Since this apparent trend is not repeated in the other track sections, it is probably caused by outlying data.

Lane Departures

Straight 2 Lane Departure Results were the same as those for Straight 1 and are presented in Appendix H (Straight 1 Lane Departures are presented above).

Straight 2 – Comfort Speed Segment Summary

Straight 2 was a good segment to see how drivers would perform in normal, unstructured driving. They were given the freedom to drive at whatever speed they felt comfortable, within the limits of the track's speed limit.

As discussed in the Mental Workload section (pg. 53), the drivers' overall mental workload levels were higher in the assisted conditions than they were in the LV and C conditions. In agreement with these results, the steering variability and "reversal" intervals were consistently more frequent during the DAS and TRAN conditions than in either of the non-assisted conditions.

This suggests that there is something about the nature of having system assistance that is adding workload to the driving task by causing drivers to make more frequent steering corrections. It is unclear whether this is a result of how the system functions or merely because driving while using the systems may involve radically different methods of interpreting and reacting to available information.

Drivers felt the most comfortable driving faster than the suggested limit in the C condition. However, drivers seemed to be more erratic in maintaining their speed during the TRAN condition than during the C, LV, or DAS conditions. As seen in other research (Brown et al., 1969; Haigney et al., 2000; Waugh et al., 2000), drivers compensated for this perceived difference in mental workload by driving slower depending on how much information they had to process.

Driving slower in the TRAN condition may suggest that drivers are compensating for the transition by slowing down during periods of their uncertainty (or while using the alternative display) and speeding up to "make up time" when they return to normal DAS assistance. These are unsafe practices, since drivers are forced to change their speed often, and have more extreme speeds (both slower and faster), which may disrupt the normal flow of traffic around them.

These trends may also suggest that drivers are unaware that the transitioning between interfaces hinders their performance. Drivers may be trying to maintain a constant speed they feel is comfortable regardless of their knowledge of the environment. This is also unsafe since drivers may believe that they are knowledgeable about their driving environment but in fact are not.

Finally, since drivers' standard deviation and mean speed did not tend to differ between the unassisted low visibility and DAS assisted conditions, it seems that drivers are just as good at driving with the system than driving without it. Drivers are only hindered when the system transitions between different interfaces. As long as the system is functioning and remains stable, using the DAS is not hurting the performance of the drivers. Therefore, if the system is providing additional information to the driver, using the system during low visibility is aiding the driver even though their performance remains the same as when they are not using it.

Drivers seemed to perform better while assisted than in the unassisted low-visibility condition, and sometimes even compared to clear conditions. Though these findings were not directly supported by the statistical tests, they suggest that if we were to gather a larger sample of drivers we may find stronger effects along these lines. If this is the case, then using the DAS (and while transitioning to the 3M system) may have allowed drivers to notice and recover from lane position departures more quickly than when unassisted.

An additional trend of note was that drivers unassisted by the system thought that lane center was slightly to the right of true lane center, and drivers using the DAS thought lane center was to the left of true lane center. This discrepancy may be due to a mismatch between where the DAS thinks the vehicle is and where the truck is in the real world. This may also be a result of the driver's individual responses to the system or a result of how the combiner was aligned. In any event, this issue should be explored further to eliminate this discrepancy.

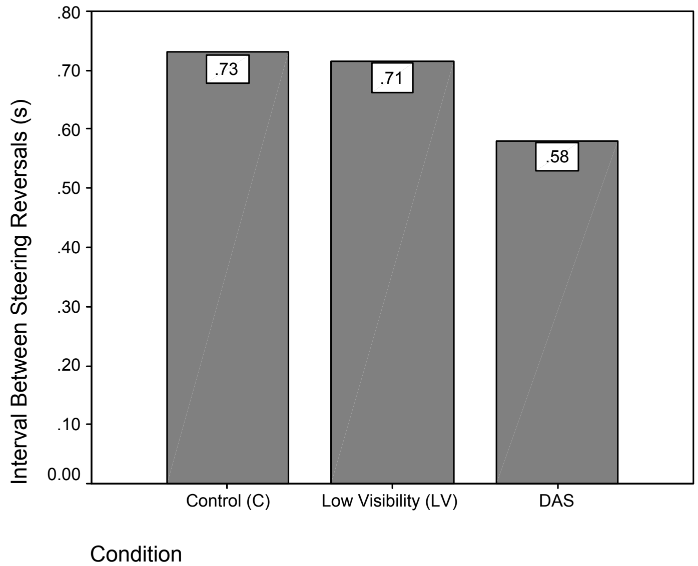
Curves

During both curves, drivers were instructed to drive at a speed that they felt most comfortable (under the emphasized 35 mph speed limit). The TRAN condition was not analyzed during the curves because transitioning from the DAS to the 3M system was disabled during these road segments.

Steering

Standard deviations of steering wheel position collected during the curves were not analyzed for two reasons. First, while driving the standard radius curves, drivers did not have to make many steering adjustments. In addition, over the course of each circuit drivers always drove in the same direction, and therefore had to make two relatively short turns towards the left and two relatively long turns towards the right during each lap (see Mn/ROAD testing track schematic diagram, Figure 2.1). Situations such as these lead to unusually high overall standard deviations caused by the nature of the track itself, not due to driving performance. Therefore, these results would be hard to interpret since they are based on a low amount of steering adjustments made at two vastly different steering positions.

However, the intervals between successive steering "reversals" are not affected by these curve orientations and the intervals for each condition are presented in Figure 3.23. Again, the TRAN condition was not analyzed for the curves, since the 3M system was disabled while driving the curves.



Analysis	Comparisons	Wilcoxon Signed Ranks Test Z	*p*	Power
Effects of LV	C - LV	0.56	0.575	0.070
System Effect	LV - DAS	2.37	0.018 *	0.746
Baseline Comparison	C - DAS	2.03	0.043 *	0.495

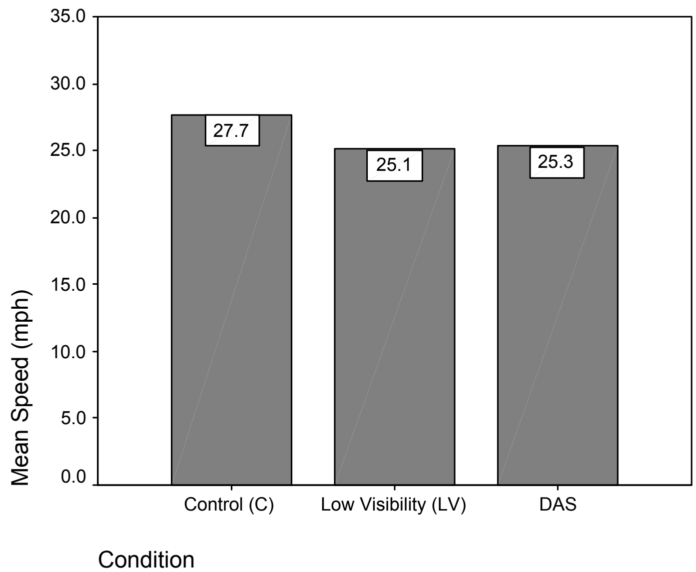
* Significant at .05 level

Figure 3.23. Graph and Wilcoxon Signed Ranks Tests for the intervals between steering wheel "reversals" on Curves

With DAS assistance, drivers made more frequent steering corrections than either unassisted condition (LV or C), as seen in the System Effect and Baseline Comparison results. This result, showing additional workload when using the DAS, may have been caused by the system's inability to display an adequate preview distance during these curves.

Speed

We analyzed the drivers' average speed to show how comfortable drivers were during each condition and standard deviation in speed as a measure of their speed variability. Figure 3.24 shows the drivers' average speeds during the curves and our analyses of the three comparisons.



Analysis	Comparisons	Wilcoxon Signed Ranks Test Z	p	Power
Effects of LV	C - LV	1.96	0.050 *	0.509
System Effect	LV - DAS	0.17	0.866	0.054
Baseline Comparison	C - DAS	2.37	0.018 *	0.867

* Significant at .05 level

Figure 3.24. Graph and Wilcoxon Signed Ranks Tests for mean speed on Curves

Drivers seemed to drive slightly faster during clear (C) conditions, but dropped down to around 25 mph for the DAS condition. This tendency was supported in the Baseline Comparison analysis. Just as driving Straight 2 at their comfort speed, while having DAS assistance drivers felt as safe as they did during the unassisted low-visibility condition.

It seems that during the curves, drivers with DAS assistance had similar tendencies as they did during the straights by driving a bit faster in the C condition, but not any faster than they would unassisted in the LV condition. This may again suggest that though it took some additional effort for drivers to use the system, using the DAS produced no differences in speed performance.

Drivers' standard deviation of speed was also measured for the curves and is presented in Figure 3.25.

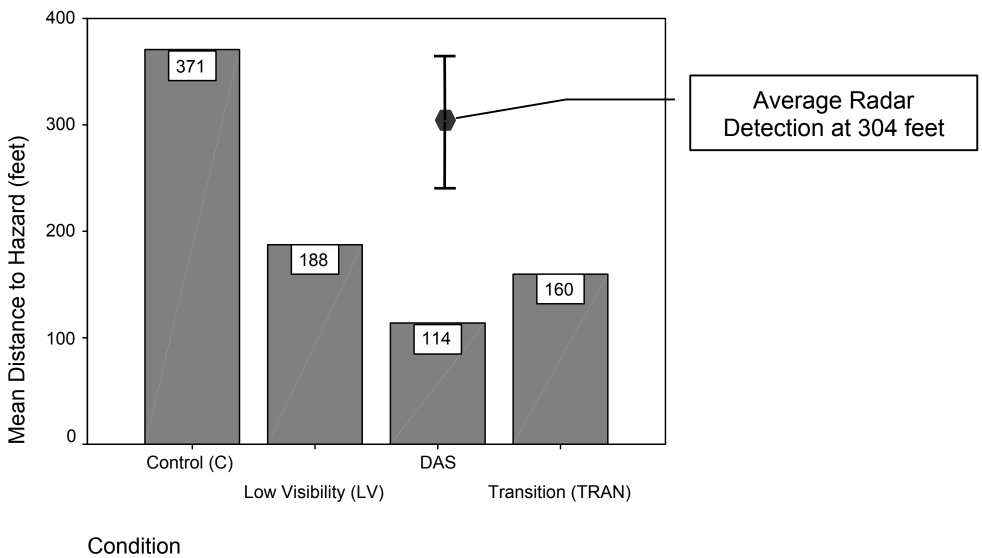
drivers with a more limited field of view, this may have made it more difficult for drivers to process the information they were presented on the HUD. In addition, speeds were reduced in both assisted and unassisted low-visibility conditions, indicating that drivers were also being more cautious.

Hazard Avoidance

Hazard performance was measured in two ways. First, it was measured in terms of the distance to the obstacle when the driver first saw it. The driver indicated this by using the left turn signal. Second, hazard performance was measured as the driver's reaction time (RT) to seeing the obstacle. This was calculated using the distance that the hazard was from the truck when the driver indicated seeing the hazard. This distance was divided by the speed at which the truck was traveling at that time to give us RT. Thus, RT is a measure of how much time the driver had to avoid hitting the obstacle.

Hazard events occurred once per circuit; therefore the following calculations are based on comparisons between individual events, one per condition.

Distance to the hazard results and the distance at which the radar detected the target can be seen in Figure 3.26.



Analysis	Comparisons	Wilcoxon Signed Ranks Test Z	*p*	Power
Effects of LV	C - LV	2.38	0.017 *	0.841
System Effects	LV - DAS	2.20	0.028 *	0.747
	LV - TRAN	1.18	0.237	0.152
Baseline Comparisons	C - DAS	2.37	0.018 *	0.925
	C - TRAN	2.37	0.018 *	0.996
Effects of TRAN	DAS - TRAN	1.52	0.128	0.269

* Significant at .05 level

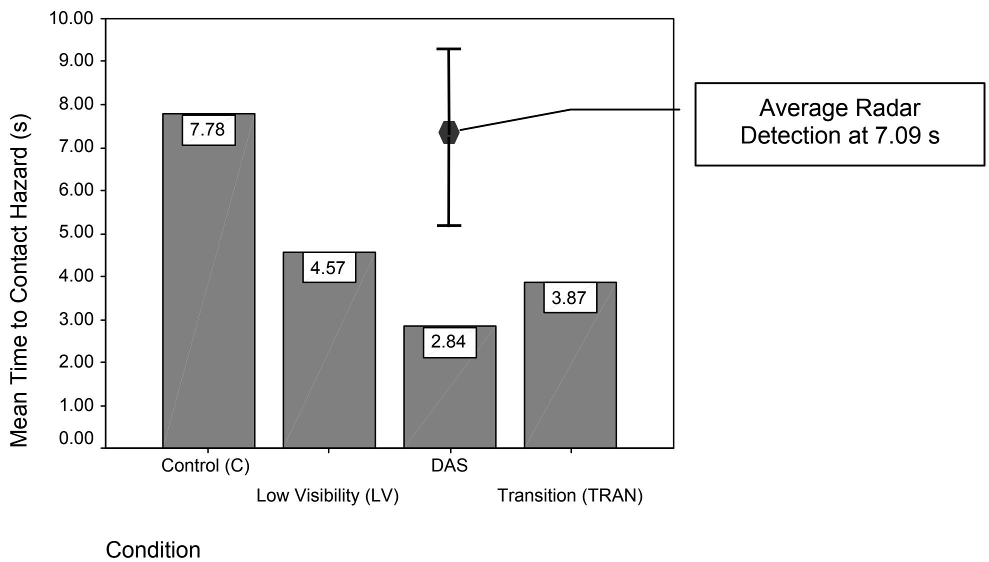
Figure 3.26. Graph and Wilcoxon Signed Ranks Tests for distance to the hazard

There were large Baseline Comparison effects between the C condition and both the DAS and TRAN conditions. Further, there was a System Effect between the LV and the DAS conditions.

Drivers spotted the hazard obstacle at much further distances during the C condition than in all three low-visibility conditions (LV, DAS, and TRAN), as was expected. The trends also suggest that drivers were the closest to the target before spotting it during the DAS condition. This is counter to what was predicted, especially considering that drivers had the added benefit of the radar to spot hazards during the DAS condition (and possibly during the TRAN condition).

Another way to quantify the hazard event is the driver's reaction time (RT) to the event. RT to the hazard was calculated as the time from when the driver reported seeing the hazard to when s/he would collide with the target (if they were to continue traveling straight towards it). This was calculated as the distance to the target at that time they reported seeing it divided by the speed at which they were traveling, thus telling us the time to contact the target.

Drivers' RT to the hazard event and the time at which the radar detected the target is contained in Figure 3.27.



		Wilcoxon Signed Ranks Test		
Analysis	Comparisons	Z	*p*	Power
Effects of LV	C - LV	2.24	0.025 *	0.787
System Effects	LV - DAS	1.52	0.128	0.387
	LV - TRAN	1.18	0.237	0.171
Baseline Comparisons	C - DAS	2.20	0.028 *	0.865
	C - TRAN	2.37	0.018 *	0.990
Effects of TRAN	DAS - TRAN	1.18	0.237	0.206

* Significant at .05 level

Figure 3.27. Graph and Wilcoxon Signed Ranks Tests for mean time to contact (RT) the hazard target

There were large Baseline Comparison effects between the C condition and both the DAS and TRAN conditions. However, there were no System Effects or Transition Condition effects.

These results seem to suggest that drivers had more time to react to the hazard obstacle in clear conditions than in all three low-visibility conditions. However, since there were no differences between driving assisted (DAS) and unassisted (LV), we cannot conclusively say that the system enabled drivers to react more quickly to the simulated stranded vehicle in low-visibility conditions.

Hazard Avoidance Summary

Overall, the hazard event results show the validity of our low visibly conditions (LV, DAS, and TRAN) to reduce the distance at which drivers could see the target obstacles. However, the DAS was not shown to increase the viewing distance of these obstacles during these conditions. On the contrary, drivers did not see the obstacles until they were closer, especially in the DAS condition.

The LV condition was shown to reduce visibility distance by 37% (see the visibility distance measure results, p.12). In the distance to hazard measure, drivers were able to spot the obstacle at 371 ft. in the C condition. Therefore, from our original visibility distance calculation drivers were expected to have seen obstacles on average at 234 ft (37% of 371 ft.) for the LV, DAS, and TRAN conditions, which was not the case.

This decrement in performance may be due to a myriad array of factors, though probably not because of the combiner's tint. This is because performance in the TRAN condition (which also utilized the HUD combiner) was not significantly different than that of either the LV or DAS conditions. However, there may be something about the display that distorts reality in such a way that is taking drivers longer to interpret warnings on the combiner than it would take to interpret seeing the obstacle with their naked eye.

The additional mental processing needed to interpret the unexpected radar warning message might help explain why drivers were slower to react in the DAS condition. Also, drivers may have been preoccupied with interpreting the DAS interface or HUD information, keeping them from scanning the driving environment as they are used to doing, and could do freely in the C and LV conditions. Further, the radar may have been slightly misaligned or the target itself aligned differently and thus the radar did not "see" it at consistent times (as evidenced by the large standard error of the radar target detection in Figure 3.26 and Figure 3.27).

Since similar trends were found for both measures, it would be interesting to explore them in more detail in a more powerful study design. It is suggested that the nature and reliability of the system, as well as the drivers' reactions to the warnings be explored in future tests of this system.

SUBJECTIVE MEASURES

The drivers' subjective responses from the test track focused on the Acceptance objective. However, whenever applicable, measures were grouped into the framework of Operability, Safety, Acceptance, and Reliability.

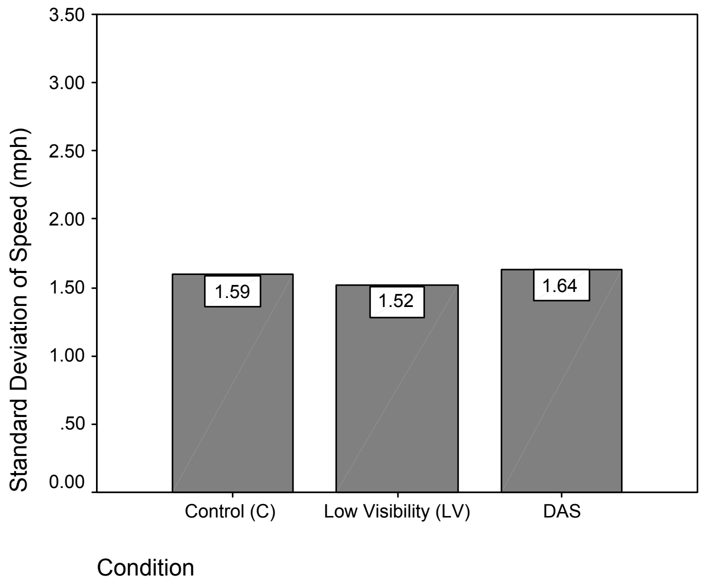
Subjective Mental Workload

The RSME is a univariate scale for rating mental effort (Zijlstra, 1993). It has been shown to be a good measure of mental effort in cases where a secondary task is presented. It was presented on paper as a single continuum from 0 to 150. Along the scale, specified points are marked with workload descriptions such as "Absolutely No Effort" (at 0), Considerable Effort (at 75), and Extreme Effort (at 115). Operators marked the place on the continuum that best described the level of workload they just put forth.

Results from the RSME are presented each of the experimental comparisons. These means were tested for statistical significance using Wilcoxon Signed Ranks Tests. All cases of statistical significance are reported with the alpha level of significance (*p*) and Power.

If a comparison was significant, this implies that the cases being compared were different in a meaningful way. Thus, if the Effect of the LV Condition is significant, that means that the C and LV conditions produced different results on the workload scale and we can infer that the two conditions were different in nature. The Power of the significance tests tells us the probability that the test is correct, where a higher number means a higher probability of being correct.

If a measure was significant, this implies that the differences in the means between the conditions in question are reliably different, and thus show a significant trend due to the differences between those conditions.



Analysis	Comparisons	Wilcoxon Signed Ranks Test Z	p	Power
Effects of LV	C - LV	0.28	0.779	0.050
System Effect	LV - DAS	0.34	0.735	0.102
Baseline Comparison	C - DAS	0.34	0.735	0.058

Figure 3.25. Graph and Wilcoxon Signed Ranks Tests for standard deviation (variability) of speed on Curves

The results indicate that the drivers' speed variation was similar in all three conditions. This matches the results from Straight 2, where drivers were allowed to drive at a speed they felt most comfortable.

Lane Position

Lane Position Results on the Curves were similar to those for Straight 1 and are presented in Appendix I (Straight 1 Lane Departures are presented above).

Lane Departures

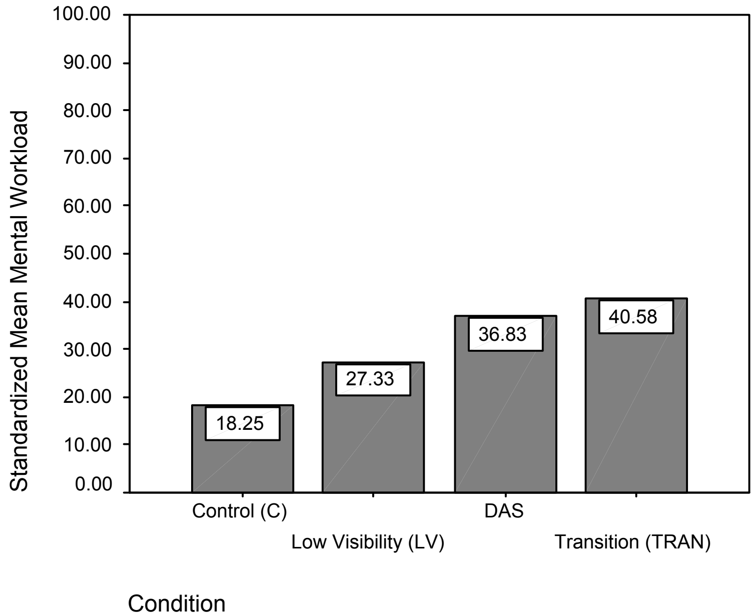
Lane Departure Results on the Curves were similar to those for Straight 1 and are presented in Appendix H (Straight 1 Lane Departures are presented above).

Curves Summary

It seemed that differences between the conditions were minimized while driving on the curves. This was most probably due to that fact that the Mn/ROAD track's curves were of a constant radius, and thus it would have been easy for drivers to take little action and still maintain satisfactory performance. This is evident in the lane position and lane departure variables, in which no significant differences or trends could be found.

There was evidence that the drivers felt they needed to put more effort into their steering while using the DAS. Drivers using the DAS made significantly more frequent steering corrections than while driving in clear or low-visibility conditions. Since driving on the curves presents

The differences between all conditions are presented in Figure 3.28.



		Wilcoxon Signed Ranks Test		
Analysis	Comparisons	Z	*p*	Power
Effects of LV	C - LV	2.55	0.011 *	0.947
System Effects	LV - DAS	2.52	0.012 *	0.792
	LV - TRAN	2.38	0.017 *	0.656
Baseline Comparisons	C - DAS	2.67	0.008 *	0.985
	C - TRAN	2.52	0.012 *	0.932
Effects of TRAN	DAS - TRAN	0.84	0.401	0.172

* Significant at .05 level

Figure 3.28. Graph and Wilcoxon Signed Ranks Tests for the mean subjective mental workload scores on the RSME for the four conditions (means were standardized to 100 point scale for graphing purposes)

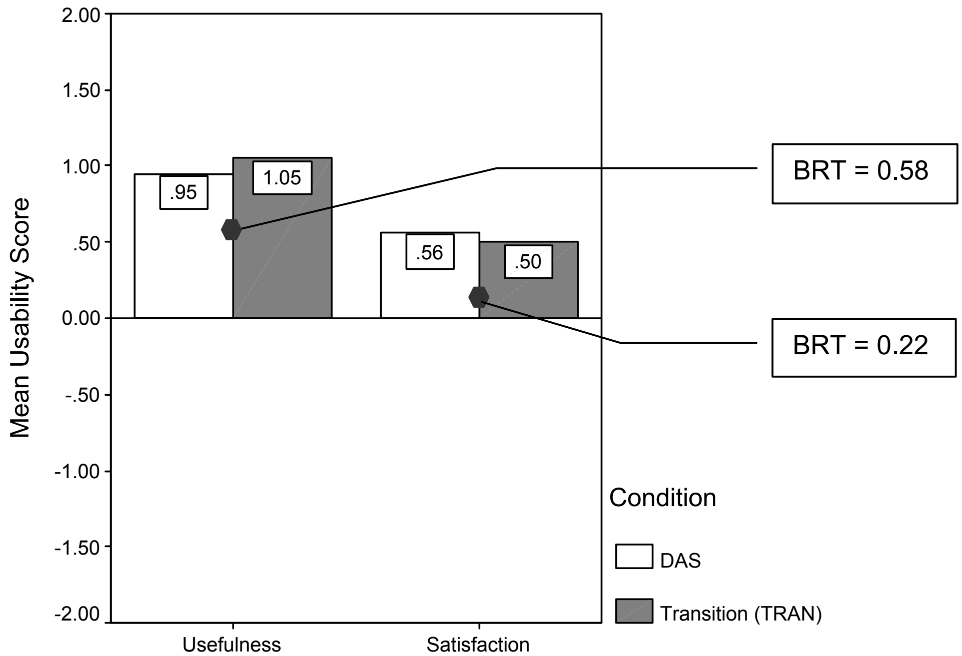
The means for the RSME showed significantly lower ratings of mental workload for the LV condition than either the DAS or TRAN conditions. This suggests that the low-visibility DAS and TRAN conditions caused drivers to have significantly higher mental effort levels than the unassisted LV condition. Specifically, using the DAS and DAS transitioning to the 3M system presented drivers with more mental workload than driving unassisted in low-visibility conditions. This trend was more pronounced when using the system with frequent (simulated) loss of GPS fix in the TRAN condition.

Drivers did not see a difference between the mental effort required to drive the DAS and TRAN conditions. This suggests that transitions occurring due to loss of GPS signal did not cause a great amount of additional mental workload for the driver.

Overall it seems that the DAS may allow better performance at the expense of requiring the processing of additional visual information. Though assisted, drivers reported higher workload ratings for a good deal of the DAS and TRAN conditions than for the LV condition. This may be expected, since in the DAS and TRAN conditions the drivers had to process a range of visual, auditory, and haptic information that they did not have to process in the LV condition. However, drivers were able to use this information to maintain their lane position and not deviate outside of the boundaries as well as they did while driving in clear visibility conditions.

Usability

In the DAS assistance condition (DAS) with low visibility, drivers reported a mean usefulness scale value of .95 and a satisfaction value of .56 (possible range –2 to +2, see Figure 3.29). In the system assistance condition with periodic interruptions requiring transitions to the magnetic tape system condition (TRAN), drivers reported a mean usefulness scale value of 1.05 and a satisfaction value of .50.



Usability Score	Condition	Mean	Confidence Interval Low	-	High
Usefulness	DAS	0.95 *	0.358	-	1.51
	TRAN	1.05 *	0.398	-	1.70
Satisfaction	DAS	0.56	- 0.218	-	1.33
	TRAN	0.50	- 0.418	-	1.42

* Significant at .05 level

Figure 3.29. Graph and confidence intervals for the comparison of the mean Usefulness and Satisfying Usability scores in the DAS and TRAN conditions

These Usefulness and Satisfaction mean scores were tested for statistical significance using confidence intervals. If the 95% confidence interval for a particular score does not include ‘0’, this was taken to mean that the mean usability score is statistically significant. This implies that the drivers had a strong opinion as to whether the system was useful or satisfying, and if this is the case the mean in the table is followed by an asterisk (*).

Overall it seems that drivers rated both implementations of the system (DAS and TRAN) useful, but did not find them as satisfying to use. The scale scores for the two conditions (DAS, TRAN) were compared using non-parametric tests (Wilcoxon Signed Ranks Test). Results indicated that there was not a difference between the system configurations for either Usefulness or Satisfaction measures.

Drivers found that the system was quite useful in both the DAS and TRAN conditions, however they did not feel that the system was satisfying. This suggests that drivers felt the system provided useful information in both conditions, however they seem to want a more satisfying implementation. Further questions relating to what the drivers find useful and what they might find more satisfying are explored in the Interview sections below.

As a comparison, scores from a recent Bus Rapid Transit (BRT) study have been added to the graph (Ward et al., 2003). During the BRT study a similar assistive system to the DAS, called a Lane Support System (LSS), was used to assist bus drivers navigate safely in dedicated bus shoulders. However, drivers in the BRT study did not experience using the system in low-visibility conditions as the snowplow operators did.

There were a few differences between the assistive systems used in the two tests. First, the LSS had a steering assist mechanism consisting of a steering wheel actuator to aid in minor steering adjustments. Also, the LSS had a virtual mirror which used side-mounted sensors to sense vehicles to the immediate left of the bus, and showed images on a small display to notify the driver of their presence in the next lane. The LSS also did not have audio lateral warnings as the DAS does.

The comparison of these results shows that drivers in our study had a similar pattern of rating the system as more useful than satisfying. However, our plow drivers saw the DAS overall as more useful and more satisfying (in either DAS or TRAN conditions) than the BRT drivers did. This suggests that drivers find the system more useful and satisfying after having used it in low-visibility conditions. The comparison also shows that it is not just our plow drivers who find the current implementation of the DAS useful yet not significantly satisfying.

Trust

These ratings were used to derive measures of trust in the system as well as additional results relating to the drivers confidence in the system. The trust measures relate to the following four trust dimensions:

- Performance – expectation of consistent, stable, desirable performance/behavior of the system
- Process – understanding the underlying qualities that govern behavior of the system
- Purpose – the underlying motives or intent of the system
- Foundation – how the system is related to natural laws and social order

Figure 3.30 shows the mean scores of the DAS and TRAN conditions for the four trust dimensions. The scores for the two conditions were compared using non-parametric tests (Wilcoxon Signed Ranks Test). Results indicated that there was not a difference between these system configurations for the Performance measure, Process measure or Purpose measure. Drivers also did not report a significant difference in their confidence in the system.

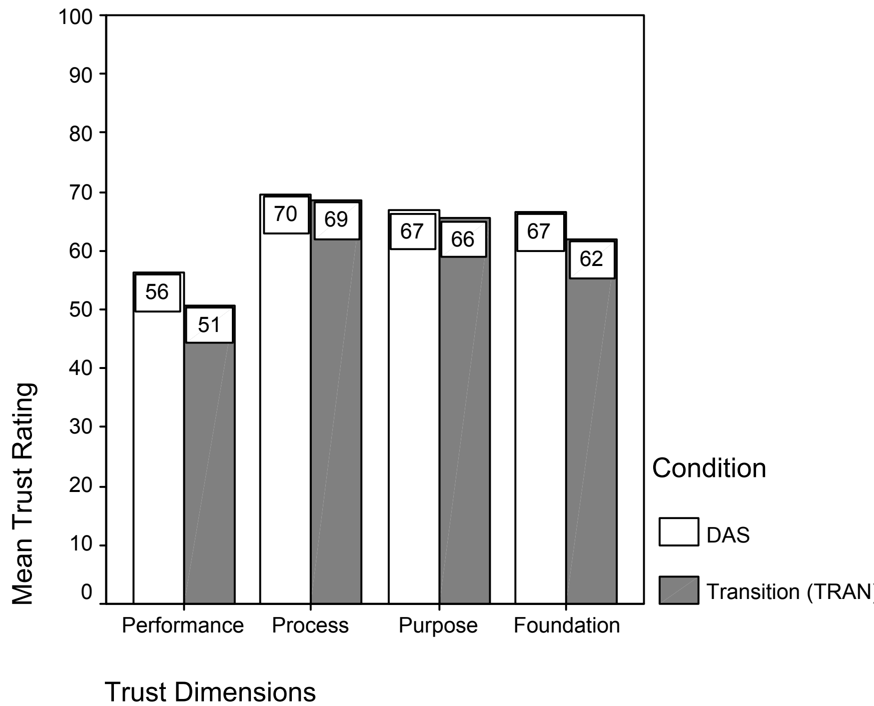


Figure 3.30. Mean ratings of the four Trust Dimensions.

This suggests that the drivers did not feel there was a difference between the DAS and TRAN conditions in relation to their expectations of performance, understanding how the system behaved, or the underlying intent of the system. They also seemed to feel confident in the system during the periods of frequent loss of signal. Overall, the drivers trust in the system was relatively high and constant over both conditions and the four trust dimensions.

There was a significant difference between the DAS and TRAN conditions for the Foundation trust measurement [$W_Z = 2.03$, $p = .042$], which is a measure of how the driver trusts the system as related to their perception of the natural order of the world around them. This shows that the drivers were more trusting of the DAS while it had a stable GPS fix (DAS condition) than they were when it frequently lost the GPS fix (TRAN condition). This also suggests that if the system performs as it did in the TRAN condition, drivers will be less trusting of the system in general, even if a backup system is available.

DAS and TRAN Interviews

Below are the compiled interview responses from the track testing conditions involving the DAS and TRAN conditions. First the graphs and analyses of the scaled responses are presented followed by open-ended comments. Though these results are based upon the 9 drivers who participated in the track test, only eight responses are presented since one driver was unable to complete the DAS condition and another was unable to complete the TRAN condition.

For both of these sections, the results have been organized by the evaluation objectives. These objectives are:

- Operability: These questions refer to how well the drivers could learn and remember how to use the system.
- Safety: Drivers' opinions of the safety of the system describe how they feel the system reduced their risk of encountering hazardous situations and crashing. Therefore, these questions relate to how distracting the system is and how safe they felt using it.
- Acceptance: These questions asked if the drivers liked how the system performed, if it helped them drive and plow, and whether they would use it in 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 reliability and dependability of the system over time. This includes drivers' opinions on how the system functioned over time and what parts of the system they found useful or functions they thought were missing.

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 on the test track. Drivers rated their agreement on this scale: 1 = Strongly Disagree; 2 = Disagree; 3 = No Opinion; 4 = Agree; and 5 = Strongly Agree. This scale of agreement is considered to range from .5 above to .5 below each rating. For example, an average rating of 3.13 is considered equivalent to 'no opinion' and an average rating of 3.63 is considered equivalent to 'agree' (as in Figure 3.31).

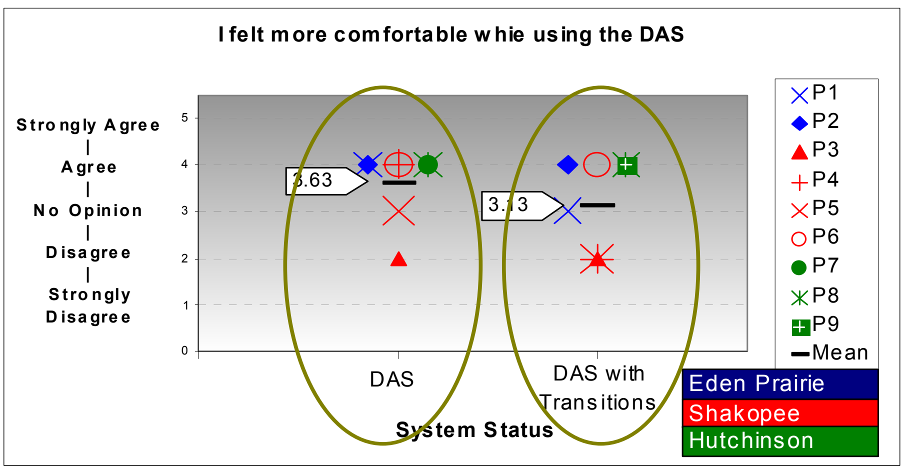


Figure 3.31. Condition Effects

Each driver's response is graphed so as to show effects due to DAS condition. If two drivers at the same station respond similarly, their icons will overlap, such as with the Hutchinson drivers in both System Statuses of Figure 3.31. Portions of the concealed icon are visible around the concealing icon. Also, even though geographic trends are not discussed, responses were grouped by home station. The means of the responses in each period are also presented.

From these results, effects by condition are reported. These show how opinions of the system differed from using the system when it has a consistent GPS fix to when it does not and has to transition between the full DAS and the 3M magnetic tape system. Comparing the means of the data from DAS and TRAN conditions will show the effects of these transitions (highlighted in Figure 3.31). These means were tested for statistical significance using non-parametric tests (Wilcoxon), however none of the results were statistically significant. Also, based on the small number of drivers interviewed (nine) and due to circumstances limiting the number of responses per condition (eight), the power of the results is low [power = {0.050 to 0.186}], and thus all differences and trends noted below should be interpreted with caution.

Operability
As a measure of perceived system operability, drivers were asked to indicate their level of (dis)agreement with the statement “Remembering how to use the DAS was difficult.“

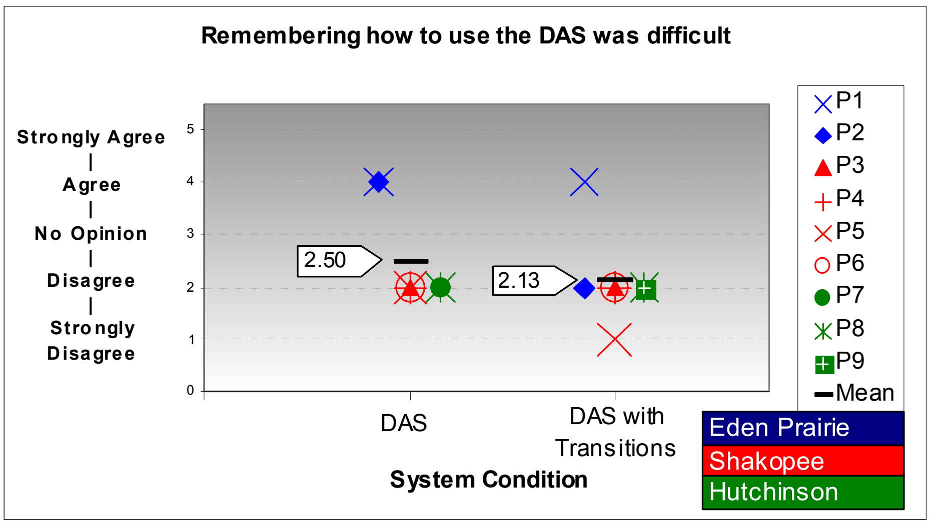


Figure 3.32. Interview data for statement “Remembering how to use the DAS was difficult”.

This question was purposely posed in a reverse manner. Though overall the drivers agreed that the DAS was not difficult to remember, it is strange that they had a slightly higher level of agreement for the TRAN condition. These results are strange because most drivers were not as familiar with the 3M magnetic tape interface that they were exposed to during this condition, yet there was more agreement that remembering how to use it was easy.

Operability Summary
Remembering how to use the system did not seem to be a problem for these drivers, even in the TRAN condition, which should have been a more novel system condition for the drivers. This 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
As a measure of perceived system safety, drivers were asked to indicate their level of (dis)agreement with the statement "Using the DAS made me a safer driver."

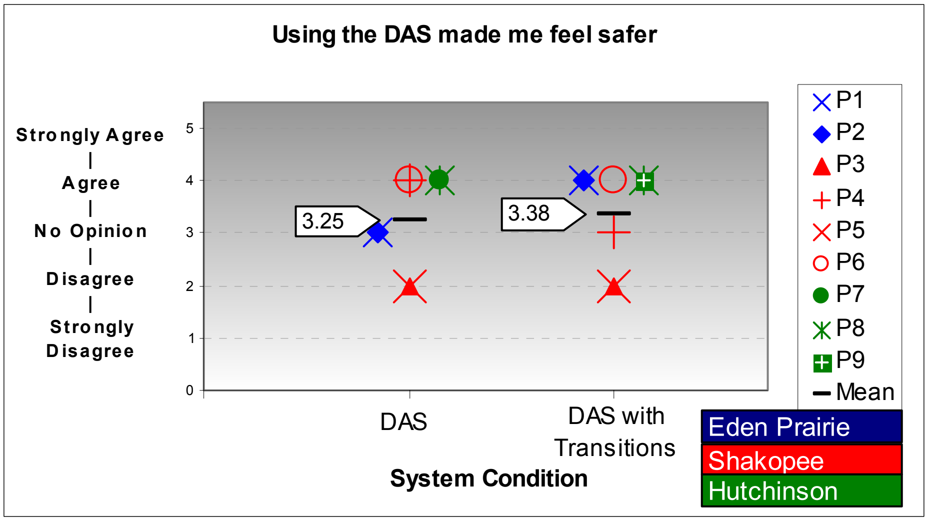


Figure 3.33. Interview data for statement "Using the DAS made me a safer driver."

The general consensus over both system conditions was that drivers had 'no opinion' of whether using the DAS made them feel like a safer driver or not. The only difference between conditions was that one more driver 'agreed' that the system made them feel like a safer driver in the TRAN condition than in the DAS condition. This suggests that drivers are not sure of the overall safety benefit from the DAS.

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

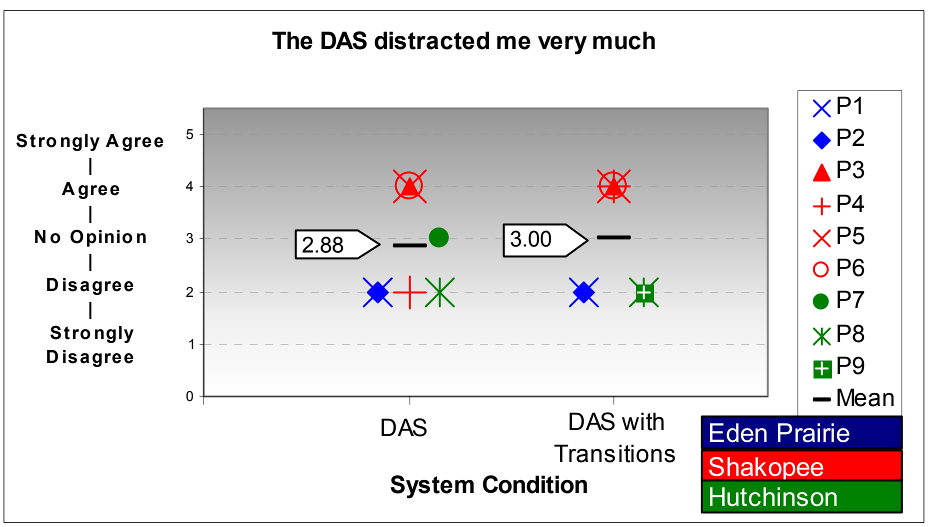


Figure 3.34. Interview data for statement "The DAS distracted me very much."

Again, the overall consensus was to have 'no opinion' on whether the DAS distracted the drivers very much. One driver who 'disagreed' that the system was distracting in the DAS condition 'agreed' that it was distracting in the TRAN condition. The averages lend some support to the theory that the transitions do not distract the drivers very much when using the system.

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

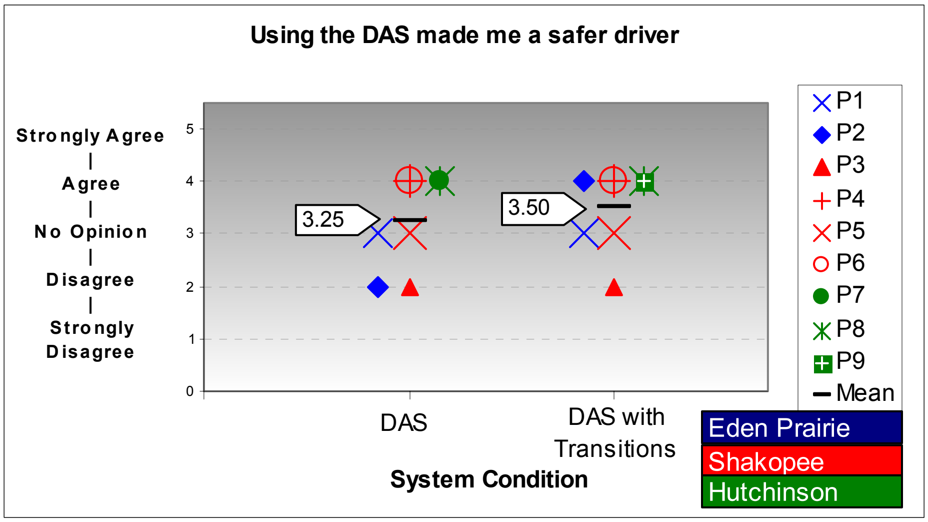


Figure 3.35. Interview data for statement "Using the DAS made me a safer driver."

Drivers had 'no opinion' of using the DAS making them a safer driver in the normal DAS condition and drivers 'agreed' that it did make them a safer driver in the TRAN condition. This difference is due to one driver changing their opinion, and in reality shows that most drivers felt the same about their safety with the system in both conditions. For this one driver, having the 3M magnetic tape system made him/her feel safer because in the field test he/she probably did not have this additional system, and here on the track they had guidance when their GPS fix was lost.

Safety Summary

Drivers did not have an opinion of whether the DAS helped make them safer while driving. This is counter-intuitive to findings above, where drivers reported that the system helped them navigate during poor-visibility conditions. Drivers may see the system as improving their ability to navigate but not in helping them improve safety.

Acceptance – Trust

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

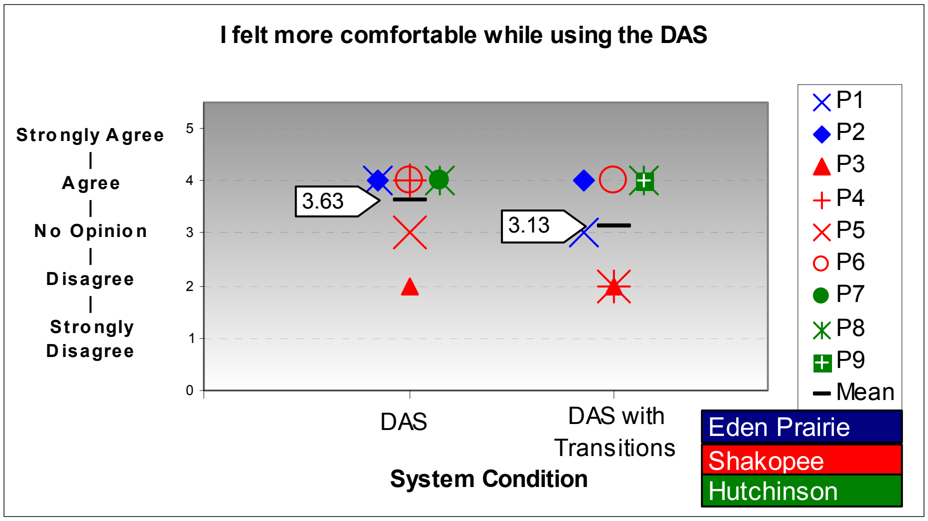


Figure 3.36. Interview data for statement "I felt more comfortable while using the DAS."

The addition of the transitions caused more drivers to disagree that the system made them feel comfortable. Indeed, two drivers who 'agreed' that the system made them feel comfortable in the DAS condition 'disagreed' in the TRAN condition. Even in the TRAN condition, drivers still averaged 'no opinion' with a majority agreeing that they felt comfortable using the system. This suggests that drivers may be used to the system transitioning (to nothing or to the magnetic tape system) from the field testing and feel comfortable because of it.

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

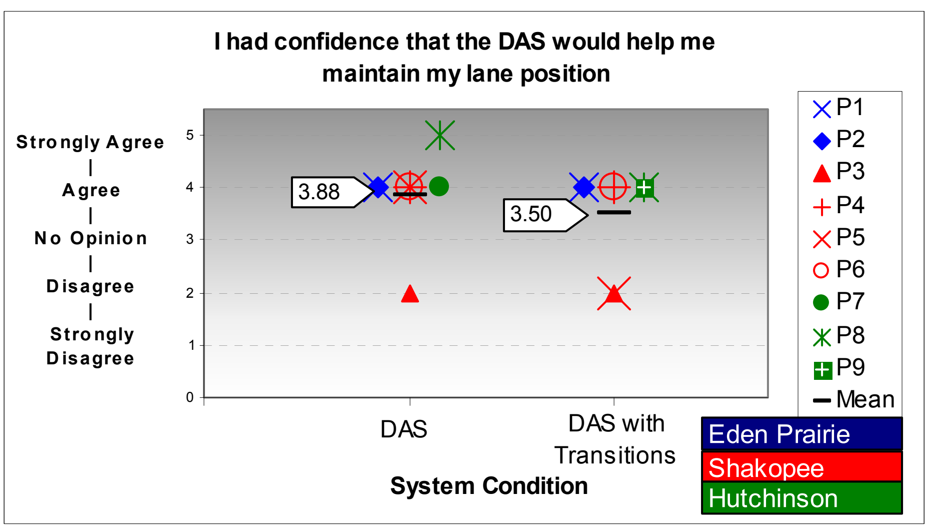


Figure 3.37. Interview data for statement "I had confidence that the DAS would help me maintain my lane position."

In both conditions, drivers agreed that the DAS would help them maintain their lane position. Two drivers who 'strongly agreed' (P8) or 'agreed' (P5) to having confidence in the DAS condition changed their opinions towards disagreement in the TRAN condition, indicating that some drivers were less confident when the GPS became less stable. Overall, drivers were in agreement to being confident in the DAS.

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

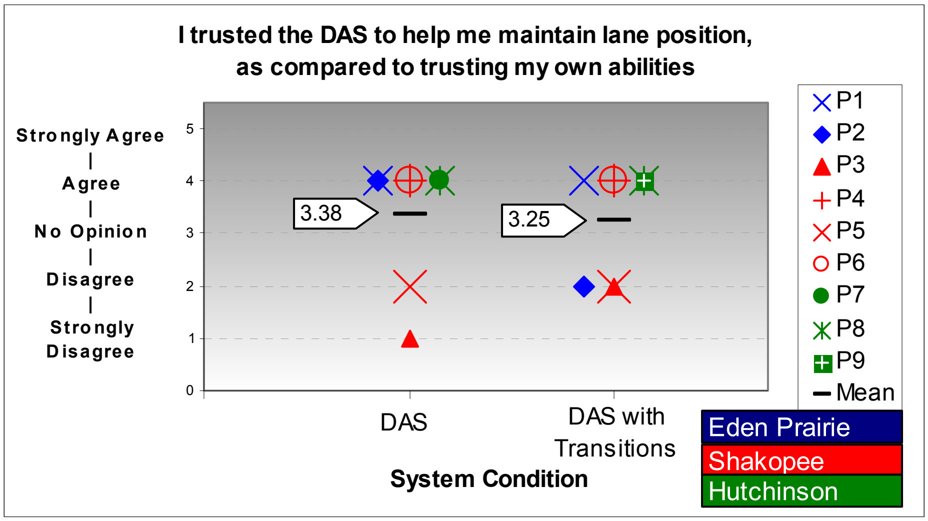


Figure 3.38. Interview data for statement "I trusted the DAS to help me maintain lane position, as compared to trusting my own abilities."

Opinions were mixed for both conditions when drivers were asked if they trusted the DAS to help them maintain their lane position, as compared to trusting their own abilities. Though the average was to have 'no opinion', most drivers either 'agreed' or 'disagreed' to trusting the system. One driver 'agreed' to trusting the system in the DAS condition but then 'disagreed' in the TRAN condition. This suggests that for this driver the unstable transitioning of the DAS caused him/her to lose faith in the system.

Acceptance – Trust Summary

Drivers trusted and accepted the system in the both DAS and TRAN conditions after driving it on the test track. This suggests that after using the system and understanding that the GPS fix may not be completely stable, most drivers are still willing to use the DAS and trust that it is giving them accurate information. Some drivers however, are put off by this instability in the system and will not feel comfortable regardless of GPS condition

Acceptance – Usability

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

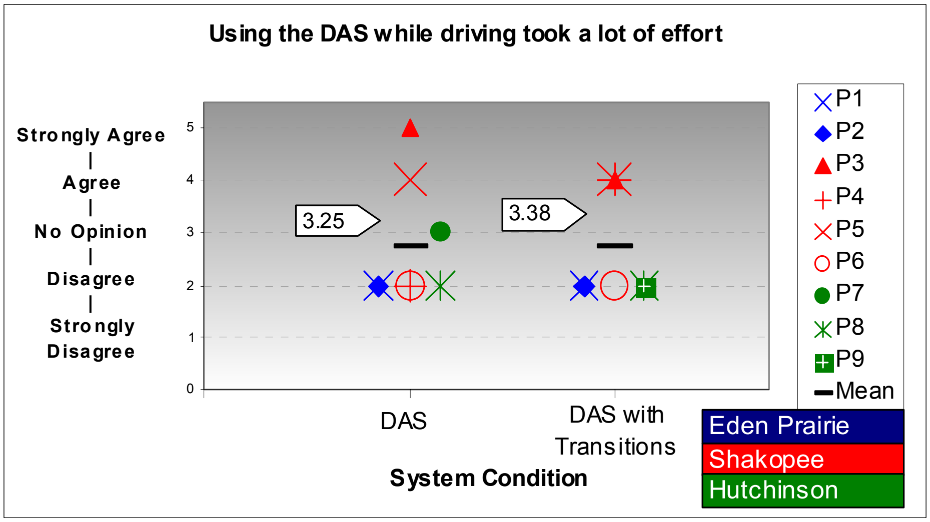


Figure 3.39. Interview data for statement "Using the DAS while driving took a lot of effort".

This question was purposely posed in a reverse manner. Averages showed that drivers had 'no opinion' as to whether using the DAS while driving did not take a lot of effort, and this lack of opinion remained in the TRAN condition. However, five out of the eight drivers in both conditions agreed that using the system did not take a lot of effort, while only two consistently disagreed. This stability in responses suggests that drivers' views on the effort it takes to use the system are GPS-stability independent, meaning they will think it takes the same amount of effort regardless of how the DAS is working at any particular time.

As a measure of perceived acceptance of the system, drivers were asked to indicate their level of (dis)agreement with the statement "The DAS was useful in poor visibility."

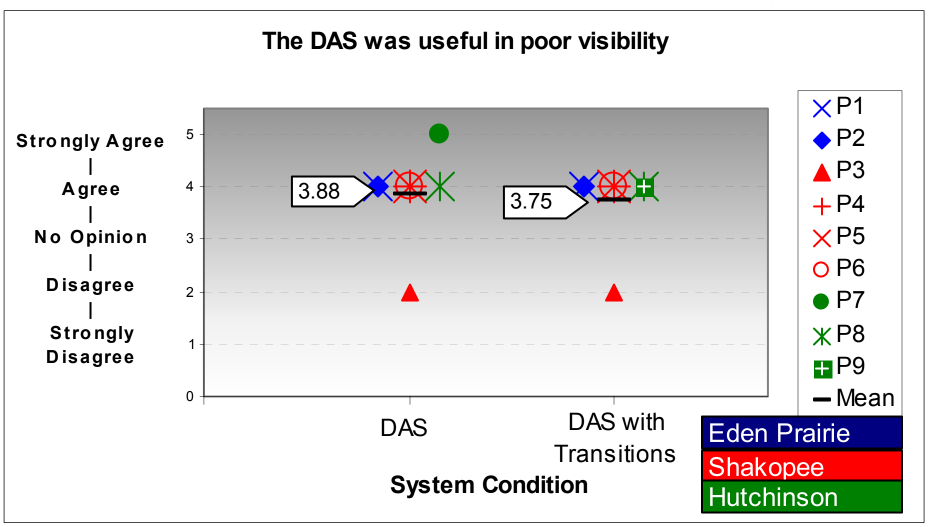


Figure 3.40. Interview data for statement "The DAS was useful in poor visibility."

Drivers agreed that the DAS was useful in poor visibility for both the DAS and TRAN conditions. All drivers who completed both conditions did not change their agreement or disagreement, suggesting that drivers think the system is useful in poor visibility regardless of GPS system condition.

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

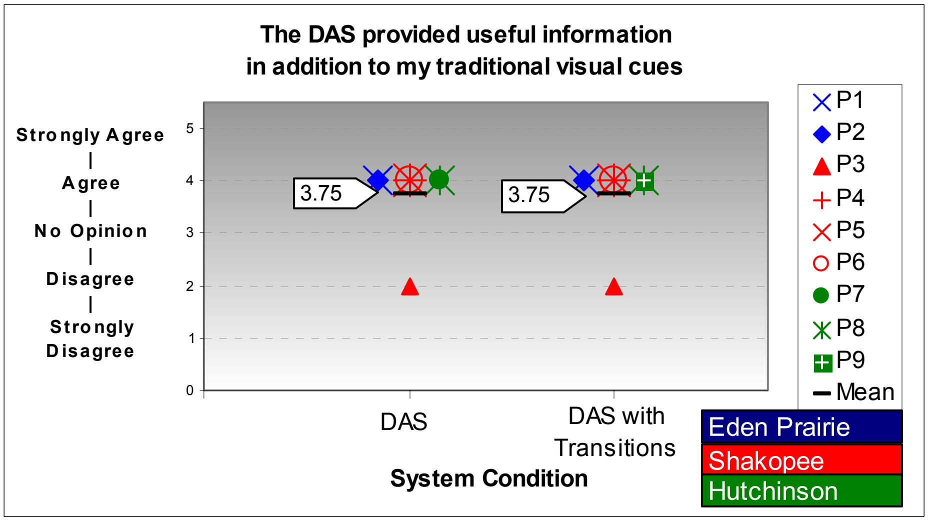


Figure 3.41. Interview data for statement "The DAS provided useful information in addition to my traditional visual cues."

Regardless of system condition, drivers agreed that the DAS provided useful information in addition to their traditional visual cues. Apparently, it does not matter to the drivers whether the system has a GPS fix the entire time or whether it periodically loses this fix; they feel the system provides useful information that supplements their view of the road.

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

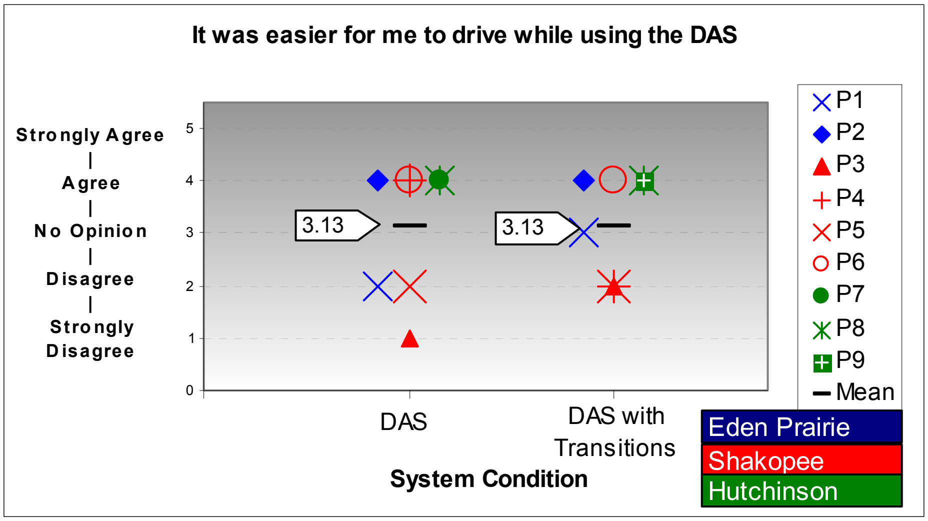


Figure 3.42. Interview data for statement "It was easier for me to drive while using the DAS."

Overall means suggest that regardless of the system condition, drivers had 'no opinion' on whether it was easier for them to drive while using the DAS or not. Only one driver 'agreed' during the DAS condition, then changed their opinion to 'disagree' in the TRAN condition. Also, two drivers in the DAS condition who 'disagreed' with the statement changed their opinions more towards 'agree' in the TRAN conditions. This was not expected to happen, since more disagreement was expected in the TRAN condition than in the DAS condition due to the loss of GPS fix.

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

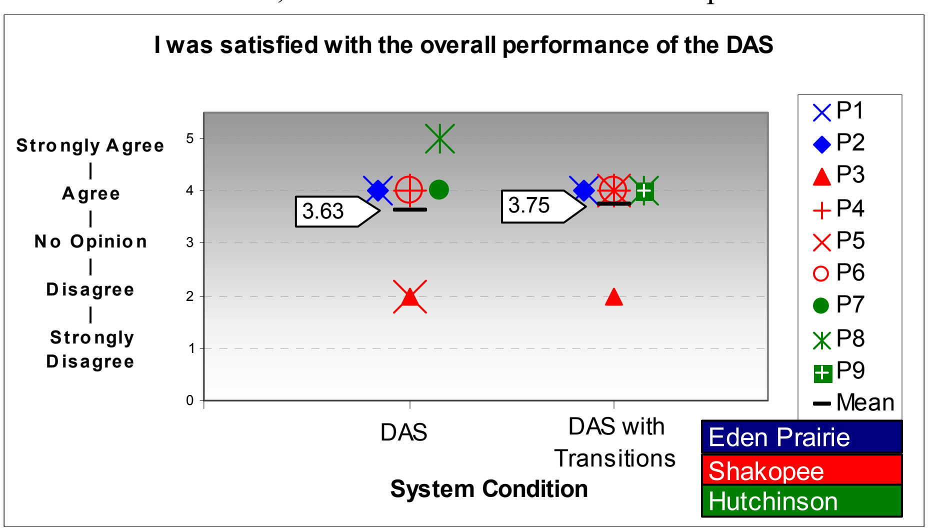


Figure 3.43. Interview data for statement "I was satisfied with the overall performance of the DAS."

In both conditions, drivers agreed to being satisfied with the overall performance of the DAS. Apparently, it does not matter to the drivers whether the system has a GPS fix the entire time or whether it periodically loses this fix; they are still satisfied with the performance. One driver changed their 'disagreement' with their satisfaction of the system in the DAS condition to 'agreement' in the TRAN condition. This may suggest that this driver sees the system as performing better when it is in a more realistic context (that of losing the GPS fix).

Acceptance – Usability Summary

Overall it did not seem to matter whether the drivers were using the DAS continuously or with frequent loss of GPS fix; drivers tended to be accepting of the current DAS implementation. They also saw benefit in using the system in poor visibility and using it in addition to their traditional visual cues, as well as finding its overall performance as satisfying. However, their opinions on the ease of using the DAS and the amount of effort to use the DAS were mixed. It is therefore recommended that improvements in the usability of the DAS (ease of use and effort to use) be explored in the next implementation of the DAS.

Reliability

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

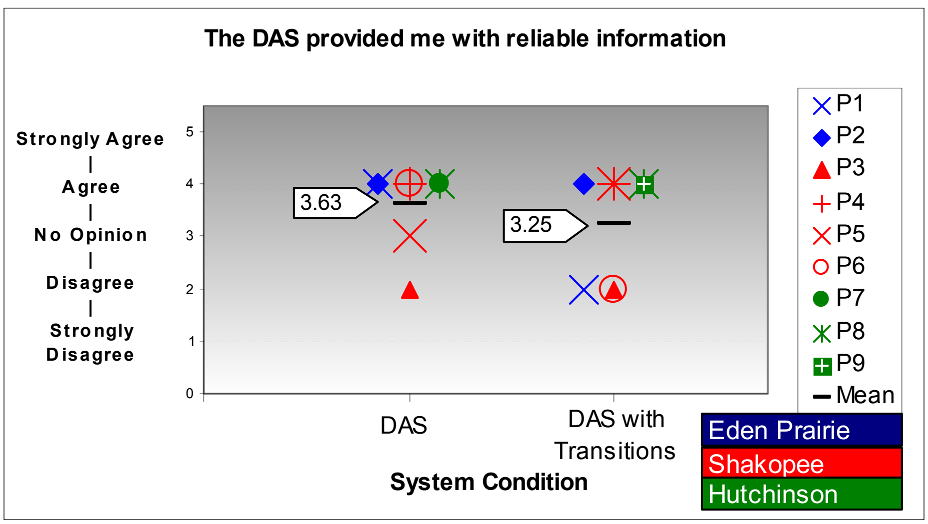


Figure 3.44. Interview data for statement "The DAS provided me with reliable information."

As shown by the group means for system status, indicated by the arrow icons, the addition of the transitions caused more drivers to disagree that the system provided reliable information. Indeed, two drivers who 'agreed' that the system provided reliable information in the DAS condition 'disagreed' in the TRAN condition. Even in the TRAN condition, drivers still averaged 'no opinion' with a majority agreeing that the system provided reliable information. This suggests that drivers may be used to the system transitioning (to nothing or to the magnetic tape system) from the field testing and/or do not think the system less reliable because of it.

Reliability Summary

With a few exceptions, perceived reliability of the DAS remained fairly constant between the normal DAS and TRAN conditions. Though the TRAN condition average is near 'no opinion', it is similar to the DAS condition. This suggests that drivers are aware and annoyed at the system when it does not function properly, but overall this seems to be something that can be adapted to or dealt with without thinking of the system as providing unreliable information.

Open-Ended Questions

Some interview questions were followed by open-ended follow up questions. A summary of these results are presented below. A detailed review of the open-ended responses can be found in Appendix J.

Safety

As a measure of perceived system safety, drivers were asked, "In what ways did using the DAS make you a safer driver?" The DAS gave drivers confidence in knowing their lane position, as stated by 38% (3/8) of the drivers in both conditions. 13% (1/8) of the drivers in both conditions also stated that it was helpful in seeing hazards with the radar.

In the DAS condition, 13% (1/8) of drivers also thought that the system was helpful on curves and that information on the combiner helped them stay alert and pay more attention. Interestingly, helping drivers pay attention was also mentioned during the TRAN condition, but the HUD was not stated. This suggests that in this instance (simulated loss of GPS fix), using the HUD made them not feel as safe as using it in the DAS condition.

In the DAS condition, 25% (2/8) of drivers did not feel they needed the system. 13% (1/8) of drivers in both conditions stated they did not trust the current implementation. 13% (1/8) of drivers in the TRAN condition noted that they had to adjust the screen often, thus indicating a safety concern.

As a measure of perceived system safety, drivers were also asked, "Why did you find it easier/more difficult to drive while using the DAS?" Half of drivers enjoyed how the DAS showed them where the road was, in both DAS conditions. Also, 13% (1/8) of drivers in both conditions liked being able to see obstacles on the combiner from the radar.

One fourth of the drivers stated that it was difficult to navigate on the curves, regardless of condition. In the DAS condition, 13% (1/8) of drivers said that the combiner gave them a headache and the system made it harder to concentrate. Though these issues were not noted in the TRAN condition, 38% (3/8) of drivers noted here that they did not trust the system completely, relying instead on their own abilities. Also, 13% (1/8) of drivers did not have confidence in the magnetic tape display's arrow.

This suggests that when the system is fully operational, drivers make a conscious effort to use it. The ill effects of getting headaches and difficulty concentrating show that small changes are needed to increase the comfort of using the combiner. However, when the system does not have as stable of a GPS fix, drivers will not choose to use and trust the system, namely the HUD, both because of poor performance and due to the undesirability of the backup display.

Acceptance — Trust

As a measure of perceived system acceptance, drivers were asked, "If you had trouble trusting the DAS, what were your reasons for this?" One-fourth of drivers in the normal DAS condition stated that they did not trust the information on the HUD, so much that they looked frequently underneath or around the combiner to check the information provided. 13% (1/8) of drivers in this condition also stated not trusting the system because it did not give adequate depth information.

In both conditions, drivers did not trust the DAS' performance on curves. This suggests that more research needs to be done on how to adequately handle curves in the DAS, including how to properly display curves in the combiner. Concerning the HUD display, drivers mentioned that getting the combiner lined up was difficult and led them to trust the system less. Also, the magnetic tape display on the combiners was also cited as being too sensitive.

As a measure of perceived system acceptance, drivers were also asked, "Would you like to have the DAS permanently installed in your truck?" This question was asked to get the drivers opinions of overall acceptance and satisfaction in the system. Whether or not drivers wanted the system installed in their truck was not necessarily a factor of condition (DAS or TRAN), as half the drivers said they would like it installed in their truck.

When asked to explain this recommendation, the most popular response from both conditions was to suggest installing the DAS in trucks assigned to plow more rural areas; areas with less ambient lighting, with less road boundaries such as jersey barriers and curbs, and with a higher likelihood of winds that might sweep snow across plow routes. Opposition to installing the system included that it was more work to use them, and that it was hard to understand parts of the display. One comment from both conditions was that they did not want the system installed as it stands now, but only if it was made more "rock solid", meaning if the technical (GPS), and physical (loose combiner, bulky size) issues were ironed out first.

Acceptance — Usability

As a measure of perceived acceptance of the system, drivers were asked, "What was most useful to you/what would be your ideal configuration of the DAS?" In both DAS and TRAN conditions, the half of the drivers thought that the ideal configuration would be using both the haptic seat lateral warnings and the HUD. The next frequently stated component was to use only the HUD, however preferences towards having the HUD dropped from 38% to 25% in the TRAN condition. This suggests that drivers preferred the HUD when it worked flawlessly and would have reservations about using it if they thought they would lose GPS fix frequently.

Using the haptic seat warnings was preferred 13% of the time in the DAS condition, and 25% in the TRAN condition. This suggests that if drivers know that GPS will not be stable, they would prefer not to have to adjust between visualizations, and rather get warnings only when they are consistent. Audio warnings were not stated as part of an ideal configuration for either DAS condition.

As a measure of perceived acceptance of the system, drivers were also asked, "What parts of the current DAS *should be removed*?" Mentioned in both conditions, audio warnings were suggested to be removed in both conditions by 13% of drivers. The HUD was also mentioned, once as a whole and another time as a recommendation to reduce the amount of information available on the combiner.

As a further measure of perceived acceptance of the system, drivers were asked, "What things *would you like added* to improve the DAS?" Making the combiner more stable was mentioned as an improvement to be made to the DAS in both conditions by 13% of drivers. Other recommendations included making the system less bulky and make it more streamline and accessible to drivers.

DAS and TRAN Interview Summary

Drivers tended to be accepting of the current Driving Assistive System implementation. They also saw benefit in using the system in poor visibility and found its overall performance satisfying. The drivers' ability to remember how to use the system suggests that their training was adequate and sufficient to help them remember how to use this system.

Half of the drivers felt that the ideal configuration of the DAS was to use both the haptic seat lateral warnings and the HUD for lane assistance. Other drivers preferred either the seat or the HUD separately, but no driver mentioned the audio warnings as a preference. When the GPS fix was unstable, drivers preferred the haptic lateral warnings. The fact that the loading task also used the audio system may have caused some drivers to dislike all audio sounds in the truck in general.

Drivers would like to see a more stable combiner and less bulky system in general, especially since half of the drivers stated enjoying seeing where the lanes were in the HUD. It was often mentioned that getting the combiner lined up was difficult and this may have led them to trust the entire system less. Some drivers also did not grasp the meaning of the changing colors of items on the HUD, especially when trying to understand how these warnings related to the real world. More research needs to be done on the meaningfulness of items displayed on the HUD to make them more intuitive, as well as methods of displaying curves in the combiner that convey more information to the driver.

Drivers trusted and accepted the system with the understanding that the GPS fix may not be completely stable all of the time. With a few exceptions, drivers seemed aware and annoyed when the system lost GPS fix in the TRAN condition, though they still thought the system provided reliable information overall. Most drivers were still willing to use the DAS and trust that it is giving them accurate information, while some drivers were put off by this instability and did not feel comfortable regardless of GPS condition. 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 (namely the HUD) 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 backup system.

Drivers overall were not sure whether the DAS helped make them safer while driving. Though they were unsure when asked if it made them safer, drivers did report in open-ended questions that they liked how the system helped them maintain lane position and to pay attention to the road. In fact, there is evidence in the mental workload findings that drivers find the system to be more mentally demanding than driving without the system. Drivers may see the system as improving their ability to navigate but not in helping them improve safety.

One-fourth of the drivers did not feel they needed the system at all, but half said that they would like it installed in their truck and most said they liked and would use at least one component if it were installed in their vehicle. However, drivers did not feel that the current implementation of the system should be installed in all trucks. This was for a few reasons, including that the system as a whole needed to mature a little more before widespread adoption. Drivers also felt that it would be beneficial to install only on select trucks and only in areas that experience true whiteout conditions.

The magnetic tape display was somewhat hard for the drivers to get a grasp on. Also, it was cited as being too sensitive, especially in comparison to the DAS HUD display that they were transitioning from/to during the TRAN condition.

Final Interview

After all four conditions were completed, drivers were given an end interview which asked them additional questions about driving that night, about the DAS, and about the magnetic tape backup system. The graphs and analyses of the agreement-rating questions are presented together with summaries of open-ended comments.

In regards to the research framework, this section is not organized by the objectives since the majority of these questions deal only with Safety and Acceptance. It is instead organized first by the system being examined, and secondly by the Understandability, Acceptance, and Performance of that system.

<u>Agreement-Rating Questions</u>

For the majority of questions, 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 their test track driving experience. Drivers rated their agreement on this scale: 1 = Strongly Disagree; 2 = Disagree; 3 = No Opinion; 4 = Agree; and 5 = Strongly Agree. A histogram is provided to show the number of drivers who responded each rating of the scale and the mean of all responses (Figure 3.45, mean indicator is highlighted).

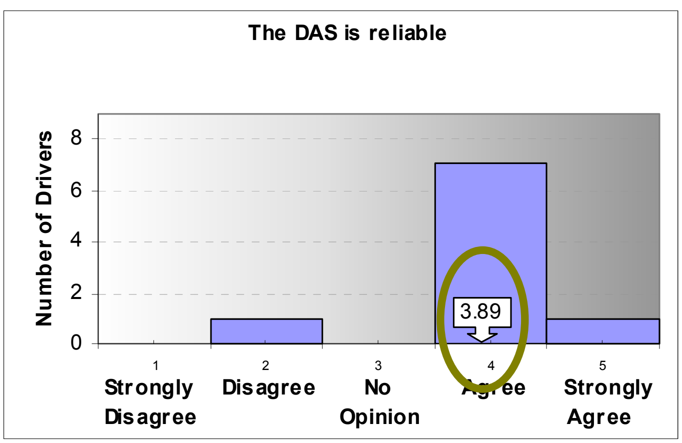


Figure 3.45. Histogram of an agreement-rating question from the final interview

These means were tested for statistical significance using confidence intervals. Means and confidence intervals for all questions are presented in the tables below. If the confidence interval does not include '3' (i.e. 'no opinion'), this was taken to mean that the mean rating is statistically significant at the .05 level. If this was the case, it is followed by an asterisk (*), implying that the drivers' opinions differed significantly from 'no opinion'; that is, they had a significant level of (dis)agreement with the statement. Specific implications are expressed in the question summaries.

Yes/No Questions

Other questions only required a 'yes' or 'no' response. Results for these questions are presented as a percentage of total driver responses, followed by the number of drivers in parentheses (e.g. if four out of nine drivers responded similarly, it is reported below as: "44% (4/9)").

Open-Ended Questions

If there was an open-ended question, subjective comments were summarized in the section below. A detailed review of the open-ended responses can be found in Appendix J.

DAS System

As reported earlier, track testing consisted of exposing the drivers to the DAS in an uninterrupted operational condition and in another condition where the DAS' GPS signal was frequently interrupted. The questions in the following section address the former, uninterrupted DAS condition.

System Understandability

Drivers were asked to assess the understandability of the DAS system under uninterrupted operational conditions. Driver responses are shown in Table 3.2.

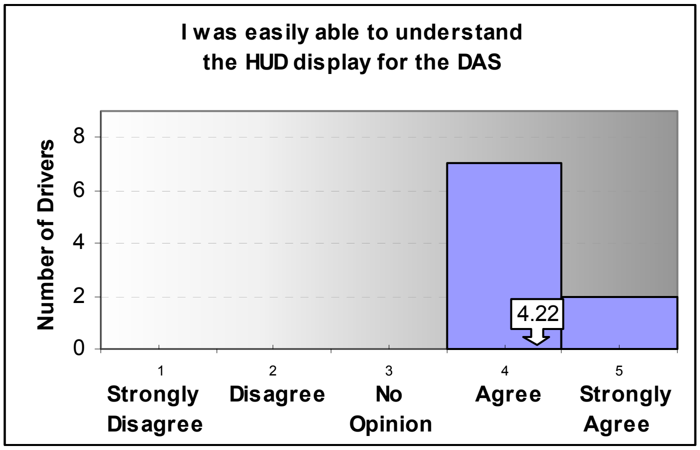
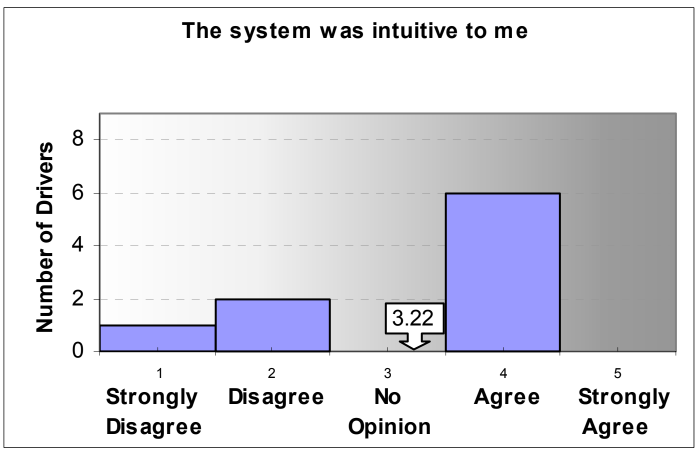
	Histogram	Mean	Confidence Interval Low - High
a.		4.22*	3.91 - 4.53
b.		3.22	2.39 - 4.05

Table 3.2. Interview data for the statements a.) "I was easily able to understand the HUD display for the DAS," and b.) "The system was intuitive to me."

Drivers reported significant agreement with respect to the understandability of the HUD (Table 3.2a). This suggests that the information on the display is presented in a form that is easy for experienced drivers to understand. For the second question, though twice as many drivers agreed that the system was intuitive (Table 3.2b), there was no overall significant agreement on driver responses to this statement.

It seems that though many drivers found it intuitive, others felt strongly that it was not an interface that someone could just walk up to and use. This also suggests that it takes some experience and training on the DAS in order to fully benefit from using it.

System Acceptance

Drivers were asked to assess the desirability of the DAS system components under uninterrupted operational conditions. Driver responses are shown in Table 3.3.

Components:	% Could See Using
HUD	67% (6/9)
Haptic Seat Warnings	56% (5/9)
Audio Warnings	0% (0/9)
Both the HUD and Seat	*22% (2/9)*

Table 3.3. Interview data for the question "Of the HUD, audio warnings, and vibrating seat warnings, which DAS components could you see yourself using on a regular basis?"

Consistent with all other results, drivers reported that they could see themselves using the HUD and haptic seat warnings, but none thought they would use the audio warnings. Two of the drivers could see themselves using both the HUD and haptic seat (as opposed to just one of these components).

Drivers were also asked to assess their perceived acceptance of the DAS system under uninterrupted operational conditions. Driver responses are shown in Table 3.4.

Drivers reported significant agreement with respect to their likeability of the HUD (Table 3.4a). Though this may suggest that they did indeed enjoy the HUD display, it may also have been a result of being exposed to a novel interface in an environment that they are very accustomed to. Drivers also reported significant agreement that the DAS might be annoying if they had to use it for 12 hours (Table 3.4b).

As a follow up, drivers were asked what would be most annoying if they had to use the system for an extended period of time. When imagining using the DAS for 12 hours, two of the drivers thought that the HUD would be hard on their eyes, and another two thought that it would be quite annoying to have to keep readjusting the combiner. Another driver replied that the radar was too sensitive at picking up objects off to the side of the road. Both of these comments, which comprise more than half of the total responses, deal with the HUD and since it is seen as an integral part of the DAS, methods to relieve these issues should be explored in depth. Once again we see that the audio warnings are cited as an annoyance, this time by two of the drivers.

A series of questions explored how the drivers felt about specific components of the DAS. Drivers were first asked what changes could be made to the HUD component to make it better. Most responses dealt with the physical implementation of the combiner itself, rather than its contents. Over half of the drivers thought that the combiner needed to be more solid. It was a frequent complaint that the screen vibrated and moved out of alignment too much while driving.

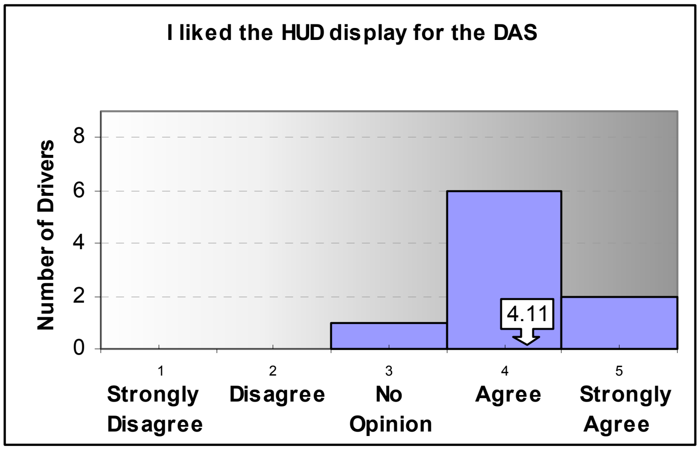
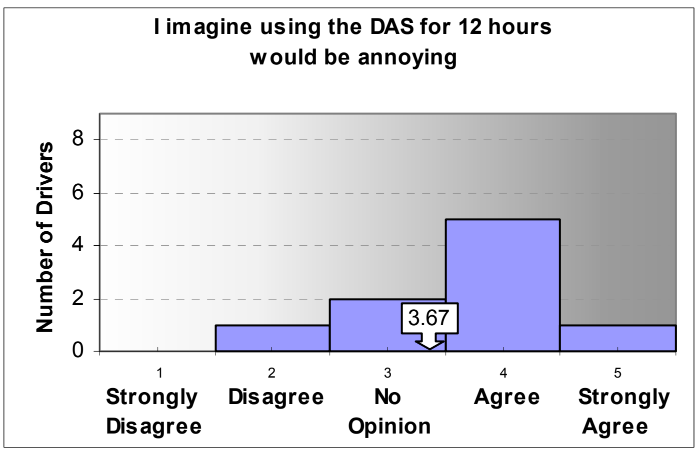
	Histogram	Mean	Confidence Interval Low - High
a.		4.11*	3.69 - 4.53
b.		3.67*	3.07 - 4.27

Table 3.4. Interview data for the statements a.) "I liked the HUD display for the DAS", and b.) "I imagine using the DAS for 12 hours would be annoying"

Three drivers thought that it should be smaller or less bulky, possibly integrated into the windshield or dash. A few drivers thought it difficult to adjust, especially while driving. Some also thought that looking through it reduced what they could see of the road. Since drivers thought favorably about HUD content, this suggests that they would be more receptive to using the system if the implementation was more stable and easier to adjust.

Drivers were then asked to assess the haptic seat component of the DAS system. Driver responses are shown in Table 3.5.

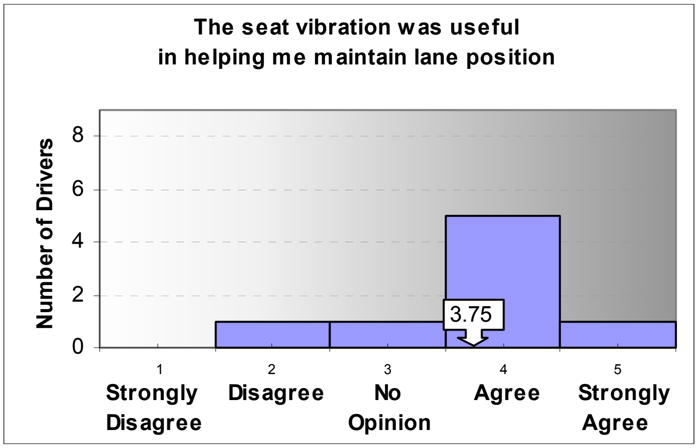
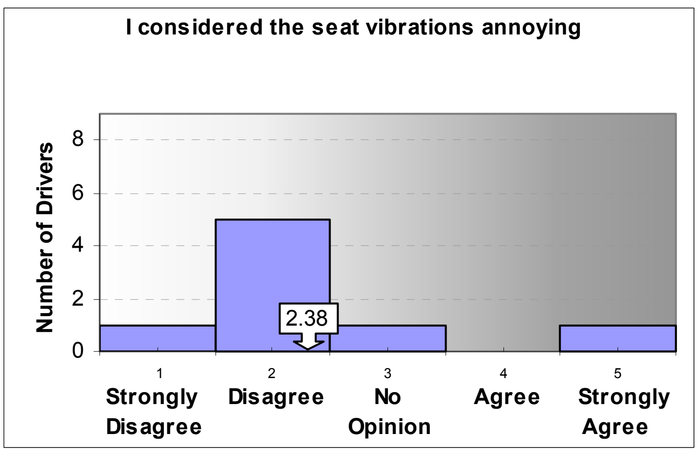
<table>
<tr><th rowspan="2"></th><th rowspan="2">Histogram</th><th rowspan="2">Mean</th><th colspan="3">Confidence Interval</th></tr>
<tr><th>Low</th><th>-</th><th>High</th></tr>
<tr><td>a.</td><td>
</td><td>3.75*</td><td>3.09</td><td>-</td><td>4.41</td></tr>
<tr><td>b.</td><td>
</td><td>2.38</td><td>0.98</td><td>-</td><td>3.76</td></tr>
</table>

Table 3.5. Interview data for the statements a.) "The seat vibration was useful in helping me maintain lane position," and b.) "I considered the seat vibrations annoying".

The first agreement-rating question (Table 3.5a) asked if the drivers thought the haptic seat component of the system were useful. Drivers reported significant agreement that it was useful. However, when asked if they thought the seat vibrations were annoying (Table 3.5b) most drivers disagreed, save one driver who strongly agreed they were annoying. Overall this suggests that the seat vibration warnings are useful but should have the option to be turned off if the individual driver feels that they are annoying or unneeded.

Drivers were also asked what changes could be made to the haptic seat component to make it better. Only positive comments were made regarding the seat warnings. For instance, one driver felt that the HUD was too much for them to handle while driving, so they preferred the seat. Another driver mentioned that if they could adjust the center-lane position, they enjoyed using this warning. From these results, it is suggested that the seat vibrations are an important and useful warning system for the drivers, as long as there is a method to adjust and/or turn off this warning as per driver preference.

Drivers were then asked their opinion of the audio warning component of the DAS system under. Driver responses are shown in Table 3.6.

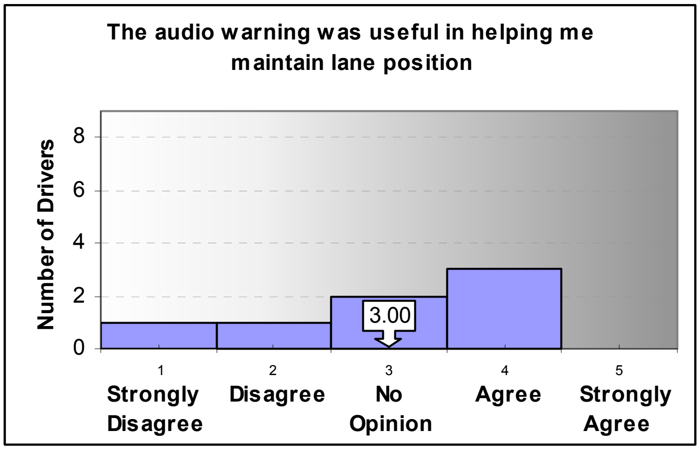
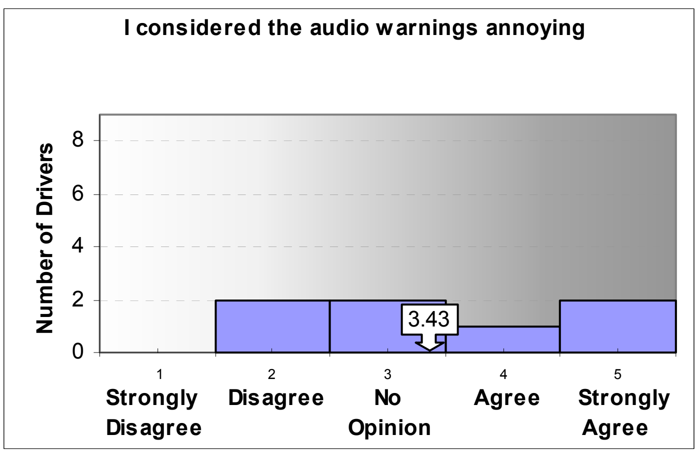
	Histogram	Mean	Confidence Interval		
			Low	-	High
a.		3.00	2.08	-	3.92
b.		3.43	2.41	-	4.45

Table 3.6. Interview data for the statements a.) “The audio warning was useful in helping me maintain lane position,” and b.) “I considered the audio warnings annoying”.

The two agreement-rating questions assess driver opinion concerning usefulness and acceptance of the audio warnings. Opinions on the audio warnings were mixed, as drivers did not report significant agreement on either question. Thus, there was no strong opinion in these questions by the drivers on whether the audio warnings were useful or annoying to them. This is somewhat contrary to the results from Table 3.3, which suggested that no drivers would use this system on a regular basis.

Drivers were also asked what changes could be made to the audio warning component to make it better. Two of drivers thought the audio warnings should be removed because they did not like how it interrupted their radio. Taking a second look at the mean scores from the agreement-rating questions (Table 3.6), drivers had 'no opinion' on whether the audio warnings were useful or annoying. Overall it seems that the audio warnings are producing negative attitudes towards the DAS as a whole.

System Performance
Drivers were asked to assess the performance of the DAS system under uninterrupted operational conditions. Driver responses are shown in Table 3.7.

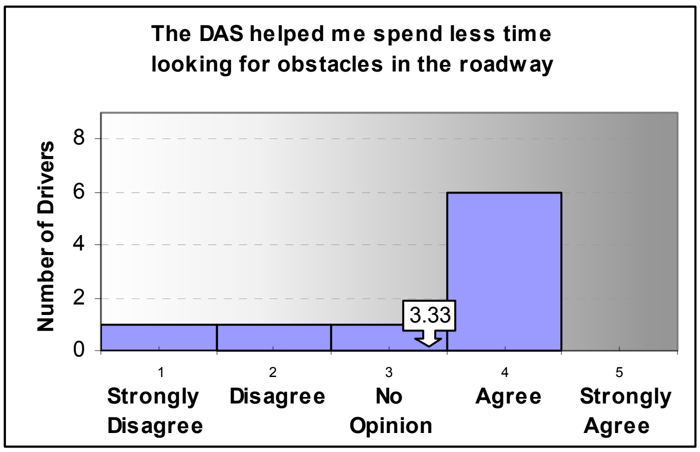
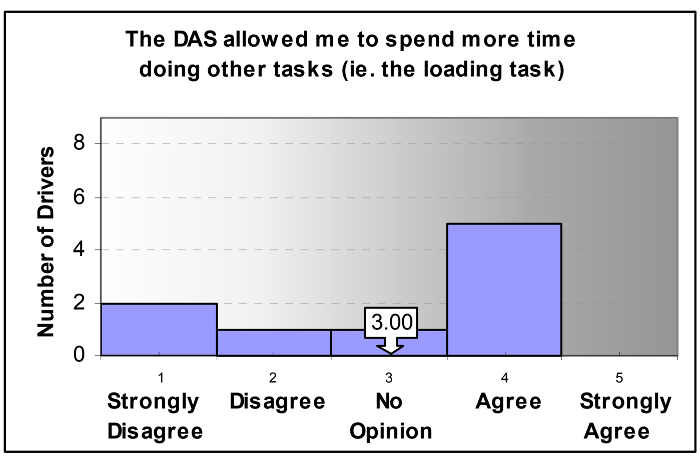
	Histogram	Mean	Confidence Interval		
			Low	-	High
a.		3.33	2.55	-	4.11
b.		3.00	2.09	-	3.91

Table 3.7. Interview data for the statements a.) "The DAS helped me spend less time looking for obstacles in the roadway," and b.) "The DAS allowed me to spend more time doing other tasks."

The two agreement-rating questions assess driver opinion on how the DAS allows drivers to spend less time worrying about driving. Opinions on these benefits of the system were mixed, and for both questions a majority of drivers agreed that the system was beneficial at allowing them to spend less time worrying about obstacles and spend more time doing other tasks. However, drivers did not report significant agreement on either question. Thus, there was no strong opinion by the drivers on whether the DAS allowed them to spend less time looking for obstacles or spending more time doing other tasks.

Drivers were also asked whether the DAS ever caused them to make a mistake while driving. One third of the drivers (33% (3/9)) said that the DAS prompted them to make a wrong action or an error in judgment.

As a follow up, drivers were asked to explain the mistake. Though one-third of the drivers reported that the DAS prompted them to make a wrong action or error in judgment, their explanations of these instances did not prove that serious. One also reported that it stopped working completely and the driver was left alone without guidance. Though this is dangerous since they were just relying on the system, it is only momentarily detrimental to driving performance since this state is what they are used to driving in without the system.

Other explanations included two drivers being unable to understand or translate the change in color (as a depth cue) into a real world interpretation of what was displayed on the HUD. 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. Even if errors were reported by a minority of drivers overall, this may be a symptom of larger problems for all drivers. Thus, it seems that the system helps drivers by not prompting them to make any serious incorrect actions or errors in judgment, but clarification is needed for the meaning of the colors used.

Drivers were then asked to assess how the DAS enhanced their performance under uninterrupted operational conditions. Driver responses are shown in Table 3.8.

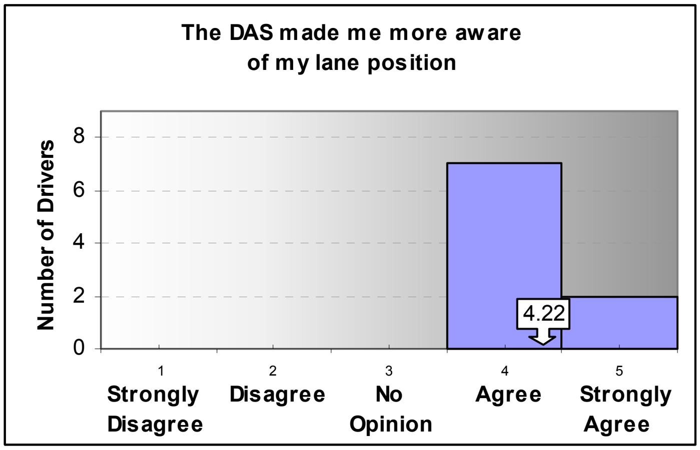
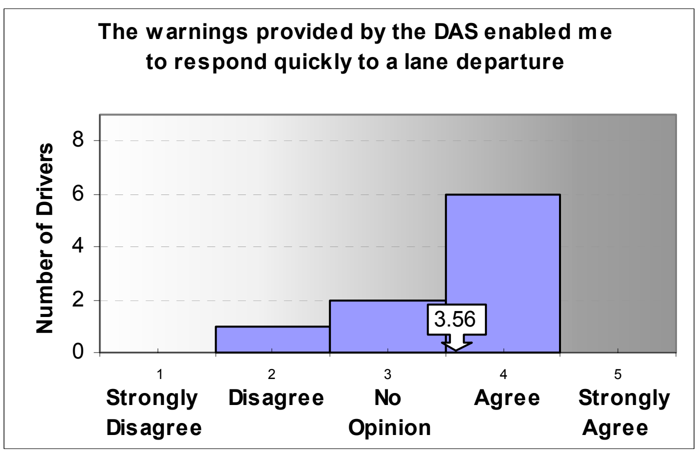
	Histogram	Mean	Confidence Interval Low	-	High
a.		4.22*	3.91	-	4.53
b.		3.56*	3.06	-	4.06

Table 3.8. Interview data for the statements a.) "The DAS made me more aware of my lane position," and b.) "The warnings provided by the DAS enabled me to respond quickly to a lane departure."

The two agreement-rating questions assess driver opinion on how well the system warned them of their lane position and allowed them to respond to lane departures. Drivers reported significant agreement with respect to the DAS making them more aware of their lane position, and the warnings enabled them to respond quickly to a lane departure. This suggests that the information provided by the DAS is useful and adequate to drivers in enabling them to know where they are on the road, and in helping them make the correct response when they deviate from it.

Drivers were asked to assess whether the DAS system helped them maintain lane position. Driver responses are shown in Table 3.9.

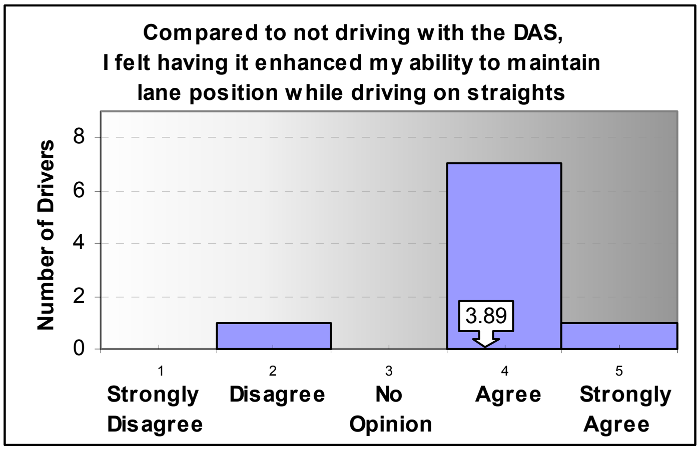
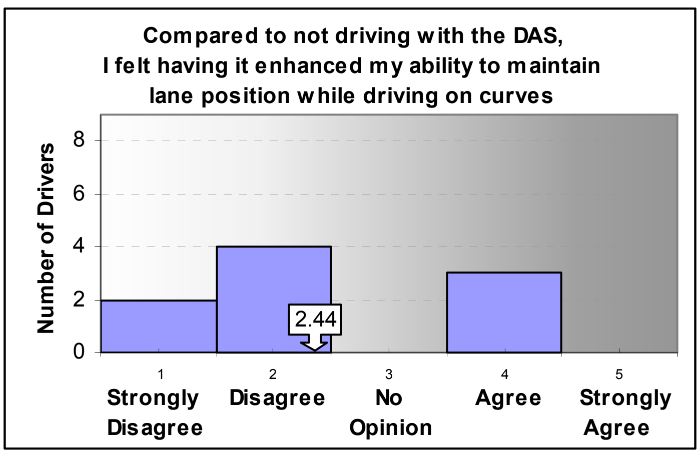
	Histogram	Mean	Confidence Interval		
			Low	-	High
a.		3.89*	3.35	-	4.43
b.		2.44	1.58	-	3.3

Table 3.9. Interview data for the statements a.) "Compared to not driving with the DAS, I felt having it enhanced my ability to maintain lane position while driving on straights," and b.) "Compared to not driving with the DAS, I felt having it enhanced my ability to maintain lane position while driving on curves."

These agreement-rating questions dealt with how the drivers felt the system helped them maintain lane position. The first agreement-rating question (Table 3.9a) asked if the drivers thought the system helped them maintain lane position while driving on straights, and drivers reported significant agreement that it did. However, when asked if they thought it enhanced their ability to maintain lane position while driving on curves (Table 3.9b), two-thirds of the drivers disagreed or strongly disagreed, though this result was not significant. Overall this suggests that the DAS was useful in helping to maintain lane position when drivers had a large preview of what was to come (in the straights) as opposed to the curves, where preview distances were severely limited.

Finally, drivers were asked to assess the perceived reliability of the DAS system in uninterrupted operational conditions. Driver responses are shown in Table 3.10.

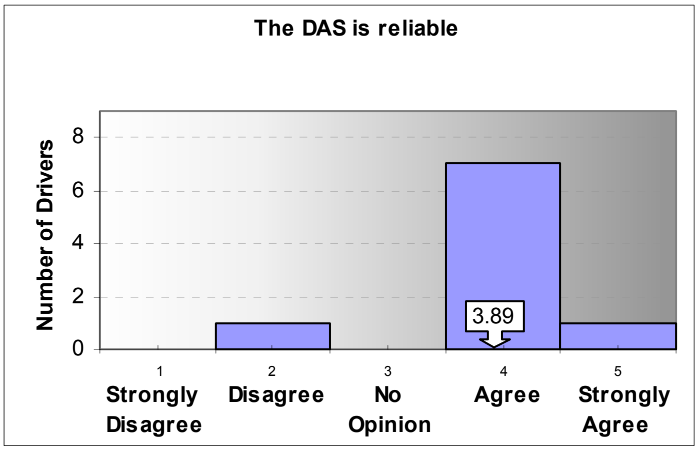
	Histogram	Mean	Confidence Interval Low - High
		3.89*	3.35 - 4.43

Table 3.10. Interview data for the statement "The DAS is reliable"

Drivers significantly agreed that the DAS is reliable. This suggests that the drivers thought the system worked consistently over time.

DAS System with Transitions

As reported earlier, another track testing condition (TRAN condition) for the DAS system would periodically simulate an interruption in the GPS signal resulting in a loss of a fixed solution. In these times where the fix was lost, the 3M magnetic tape lane detection system was simulated in the HUD.

System Understandability

Drivers were asked to assess the understandability of the HUD displays for the DAS system under interrupted operational conditions and with magnetic tape lane detection interface backup. Driver responses are shown in Table 3.11.

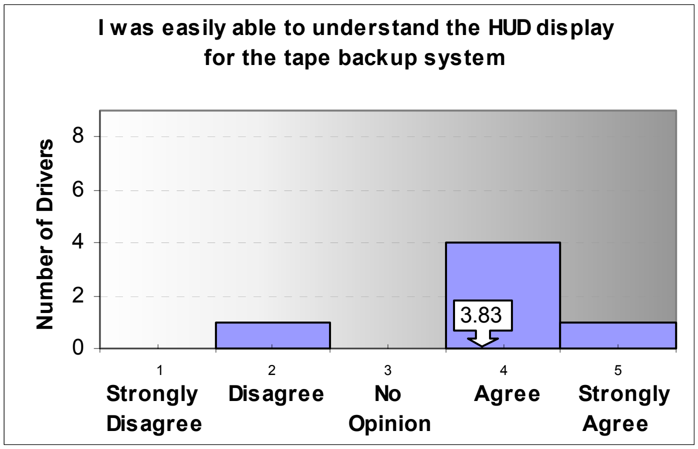
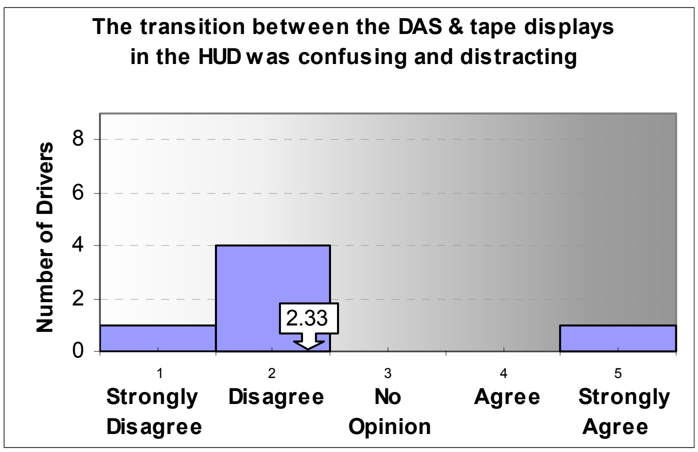
<table>
<tr><th rowspan="2"></th><th rowspan="2">Histogram</th><th rowspan="2">Mean</th><th colspan="3">Confidence Interval</th></tr>
<tr><th>Low</th><th>-</th><th>High</th></tr>
<tr><td>a.</td><td>
</td><td>3.83</td><td>2.97</td><td>-</td><td>4.69</td></tr>
<tr><td>b.</td><td>
</td><td>2.33</td><td>1.13</td><td>-</td><td>3.53</td></tr>
</table>

Table 3.11. Interview data for the statements a.) "I was easily able to understand the HUD display for the tape backup system," and b.) "The transition between the DAS & tape displays in the HUD was confusing and distracting".

The two agreement-rating questions assess driver opinion concerning understandability of the tape backup system display during the TRAN condition. Opinions on this display were mixed, as drivers did not report significant agreement on either of these questions. A majority of the drivers agreed they found it easy to understand the HUD display and that the display was not confusing or distracting, but neither of these results were significant. Thus, there was no strong opinion by the drivers on whether this tape backup system interface was understandable.

System Acceptance

Drivers were asked to assess their acceptance of the DAS system under interrupted operational conditions and with magnetic tape lane detection interface backup. Driver responses are shown in Table 3.12.

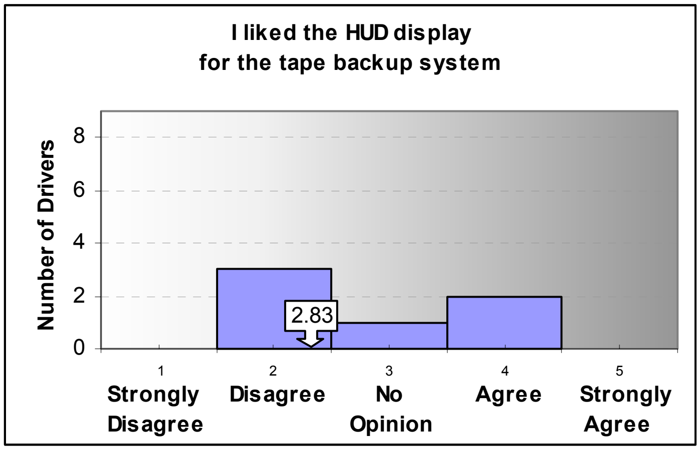
<table>
<tr><th rowspan="2"></th><th rowspan="2">Histogram</th><th rowspan="2">Mean</th><th colspan="3">Confidence Interval</th></tr>
<tr><th>Low</th><th>-</th><th>High</th></tr>
<tr><td></td><td>
</td><td>2.83</td><td>1.97</td><td>-</td><td>3.69</td></tr>
</table>

Table 3.12. Interview data for the statement "I liked the HUD display for the tape backup system"

This agreement-rating question assesses driver opinion concerning likeability of the tape backup system display during the TRAN condition. Drivers did not have a strong opinion of this display, as drivers did not report significant agreement or disagreement. Thus, there was no strong opinion by the drivers on whether this tape backup system interface was likeable.

Drivers were also asked their preference for what to display during a loss of GPS fix. Half (50% (3/6)) of the drivers reported that they would prefer to see the tape backup system on the HUD during these instances, as opposed to nothing at all.

Drivers were also asked what components or methods would be most preferable to convey these lateral warnings. Responses are shown in Table 3.13.

Components:	% of Drivers:
Haptic Seat Warnings	67% (4/6)
HUD	50% (3/6)
Audio Warnings	17% (1/6)
Other	0% (0/6)

Table 3.13. Interview data for the question "Would you prefer the tape backup system to warn you through the HUD, seat, audio, or some other method?"

The percentage of drivers stating a preference for the components is larger than 100% since some drivers preferred a combination of two components. One driver stated a preference for both the seat and audio warnings, while another would prefer both the HUD and seat warnings.

Two-thirds of the drivers reported a preference to have this warning system notify them of lane departures through the haptic seat warning system. Half of the drivers noted in their explanations that the seat was their favorite and it was the most noticeable warning. Half of the drivers reported they would prefer the HUD, and one driver had a preference for the audio system. Of these drivers, one driver had a preference for both the haptic seat and audio warnings, and another had a preference for the HUD and seat warnings. Drivers did not provide any additional alternative warning methods.

It is hard to note specific trends in driver preference of driving with the HUD implementation of the tape backup system, since only half the drivers preferred the system over nothing at all. Most probably, the half of drivers who said they would prefer to see nothing instead of this interface are probably the same ones who stated a preference for another component implementation.

Also, though the HUD was strongly represented when asked what would be a preferred warning method (Table 3.13), it was hardly mentioned at all when asked to explain that recommendation. This suggests that drivers may have been praising this implementation of the system that they used and another implementation may be more suitable. Overall it is safe to say that for this interface there are clearly people who would prefer other methods, aside from the HUD, to receive this lane departure information.

Drivers were also asked their preference for alternative ways to display lane information during a loss of GPS fix. Four drivers (67% (4/6)) reported that they would like to see some implementation of the tape backup system installed by itself in their truck.

Drivers were then asked to explain why they would or would not like this system implemented. Drivers' reasons for wanting any portion of this system installed ranged from it being simpler than the DAS to it being another useful tool in seeing the road. One driver suggested that it would be useful if it were implemented through the seat or audio, which was also recommended from another set of responses.

Those that did not like it reported problems with the display, including that it was too sensitive, that the display needed to be refined in some way, and that the normal HUD output did not match up with the tape output.

System Performance

Drivers were asked to assess the performance of the DAS system under interrupted operational conditions and with magnetic tape lane detection interface backup. Driver responses are shown in Table 3.14.

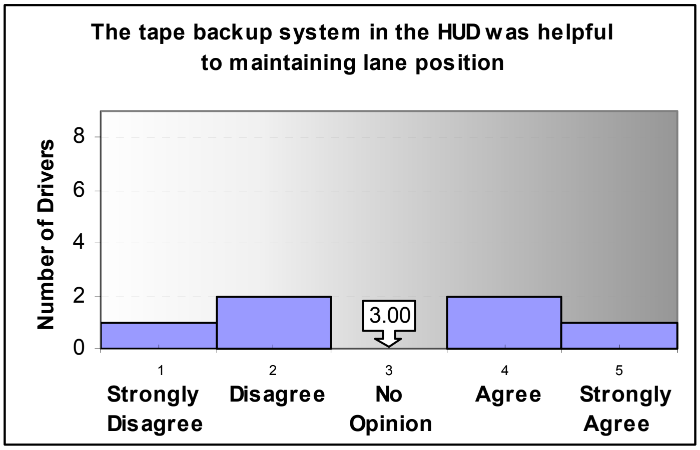
	Histogram	Mean	Confidence Interval Low - High
		3.00	1.64 - 4.36

Table 3.14. Interview data for the statement "The tape backup system in the HUD was helpful to maintaining lane position."

This agreement-rating question dealt with how the drivers felt the system helped them maintain lane position. There was no significant agreement on driver responses to this statement, as drivers were completely split on their (dis)agreement. This suggests that drivers were highly split in their opinions on whether the DAS helped them maintain their lane position in general. This means that since drivers are naturally at different ability levels and in need of different manners of assistance, the current system may not be useful for all drivers

Drivers were also asked how safe the DAS system made them feel under interrupted operational conditions and with magnetic tape lane detection interface backup. Driver responses are shown in Table 3.15.

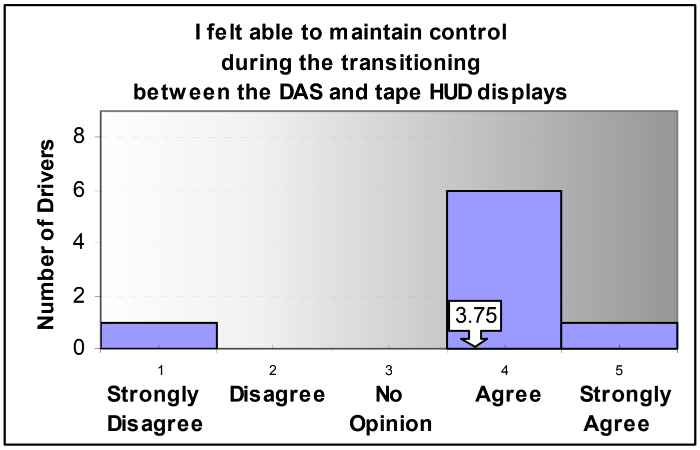
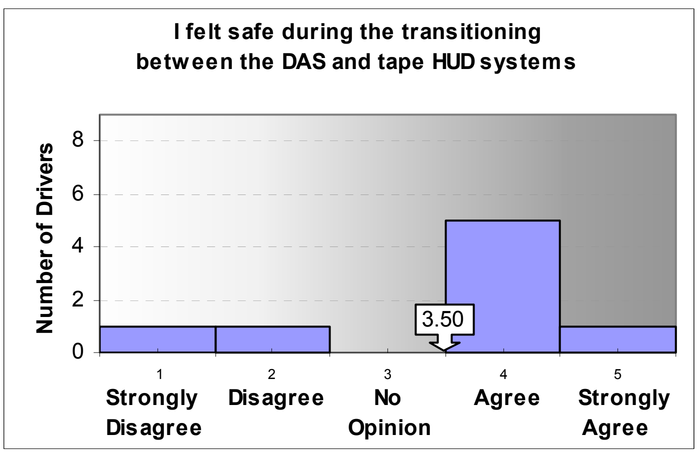
	Histogram	Mean	Confidence Interval Low - High	
			Low	High
a.		3.75	2.89 -	4.61
b.		3.50	2.53 -	4.47

Table 3.15. Interview data for the statements a.) "I felt able to maintain control during the transitioning between the DAS and tape HUD displays," and b.) "I felt safe during the transitioning between the DAS and tape HUD systems."

The two agreement-rating questions assess driver opinion concerning safety and ability to maintain control during transitions between the full DAS system and the tape backup system. Opinions on this display were mixed, as drivers did not report significant agreement on either of the two questions. Though a majority of the drivers agreed they felt able to maintain control and felt safe during the transitioning, individual drivers disagreed and strongly disagreed on both issues.

Final Interview Summary

DAS

Drivers felt that the DAS was easy to understand, but not all drivers fully agreed that it was intuitive. This is to say that drivers felt the DAS was easy to understand only once they had some experience with it; not all drivers felt that they could use the system without some training. Consistently, drivers reported that they could see themselves using the HUD and haptic seat warnings, but none thought they would use the audio warnings. Some drivers would like to simultaneously use both the HUD and haptic seat as opposed to just one of these components.

Overall, drivers reported liking the HUD, yet when asked what it would be like to use the system for one extended period of time drivers felt that the HUD would be the cause of most annoyances. Such opinions may be due to the HUD being such a novel and salient interface in their high demand work environment. When asked what could be changed about the HUD, most responses dealt with the physical implementation of the combiner itself, rather than its contents. Most drivers suggested that the combiner be more stable and the system in general take up less cab space. Some even reported that it was harder to see the road itself through the combiner, which is obviously a safety concern.

Drivers found the vibrating (haptic) seat warnings to be useful. Almost all drivers did not find the haptic seat warnings as annoying, and thus the warnings were utilized when drivers had to look away from the road. Overall this suggests that the seat vibration warnings are useful but should have the option to be turned off if the individual driver feels that they are unneeded. When asked what should be changed about these warnings, only positive comments were given (i.e. no changes were suggested). From these results, it is apparent that the seat vibrations are an important and useful warning system for the drivers, as long as there is a method to adjust or turn off or adjust the intensity of these warnings.

Opinions of the audio warnings were mixed, with no clear consensus on their usefulness or propensity to annoy the drivers. Drivers could not see themselves using this warning on a regular basis, and it was cited as being a possible annoyance if they had to use the system for an extended period of time. Drivers also did not like how these warnings interrupted their radios.

Drivers reported that the DAS was reliable and added safety to their driving environment in a number of ways. It seems that drivers thought the DAS enabled them to be more aware of their lane position and to enhance their ability to maintain lane position while driving on straights. It was also reported to aid them in responding quickly to lane departures, but strangely it was not reported to help in maintaining lane position and situation awareness in general. The system was more helpful while driving on straights than on curves where preview distances were shorter. Overall this suggests that drivers were highly split in their opinions on whether the DAS helped them maintain their lane position in general.

Drivers were not sure the DAS helped them spend less time looking for obstacles. In fact, drivers commented on not being able to translate the color differences in the HUD into real life distances. Overall, the most grievous problem was when the system stopped working due to a loss of GPS fix. In this instance, drivers had to reestablish their bearings after being dependent upon the system for aid. This is somewhat understandable as it is part of the nature of relying on GPS for guidance, however it presents the problem of keeping the drivers safe and aiding their ability to guide the truck during these transitional periods.

DAS with Transitions and Magnetic Tape Backup System

There was no strong opinion by the drivers on whether this tape backup system interface was understandable or likeable. Some of the drivers reported that they would prefer to see the tape backup system on the HUD during these instances as opposed to nothing at all, and a majority of the drivers would like to have some implementation of the system installed by itself in their truck. When asked what components or methods would be most preferable to convey these lateral warnings, a majority of drivers responded that they would like to feel the road through the haptic seat, as was previously recommended by McGehee and Raby (2002).

It is hard to note specific trends in whether drivers truly preferred this HUD implementation of the tape backup system in light of only half the drivers preferring this combined system over nothing at all. Two out of the three drivers who said they would prefer to see nothing instead of this interface also stated a preference for another component implementation. Drivers tended to think that it was too sensitive, in that the indicator would jump around on the display. Also, since the normal HUD output did not match up with the tape output, they recommended that this display be refined in some way. It is safe to say that for this interface, there are clearly drivers who would prefer other methods (aside from the HUD) to receive this lane departure information.

Final Survey

The final survey was given after all conditions were driven and all interviews were conducted. Since this survey was also given during last year's FOT, these survey results were analyzed and reported in comparison to previous findings. This survey pertained to driver's complete experience with the DAS and not just to track testing. For this reason, results from the final survey are presented with the FOT data (see Appendix K or Rakauskas et al., 2003).

4 DISCUSSION

The material presented in this discussion section is also presented with the FOT data in the main study document (Rakauskas et al., 2003).

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. 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. Even drivers who were receptive to the HUD could relate specific experiences (from 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 driving in low-visibility conditions on a test track. In doing so, driving performance, driver workload, and system performance results were drawn from these low-visibility conditions.

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, due to the small number of drivers tested in the FOT and track testing studies, there was low power and high variance for the statistical analyses, resulting in fewer 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. Help compensate for the suddenness of GPS solution loss: (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.

   The design team is currently exploring solutions to these issues.

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. Future versions that are used by a larger audience will also benefit from simple language on the interface. 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 DAS and TRAN conditions of track testing, drivers centered the truck slightly left of where they did during the C and LV conditions. This difference was consistent across both Straights.

   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. Driver 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. <u>Consider eliminating audio lane boundary warnings</u>: (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. <u>Adjusting HUD combiner brightness</u>: (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 – FOAM-SNOW SYSTEM

An Antari S100-II foam snow machine was purchased to see if artificial whiteout conditions could be simulated (Figure A-1). The machine takes a foam solution and creates foam in front of a high-powered fan. The fan blows the foam through a sock, which separates the foam into smaller, snowflake cluster-sized particles. These particles are then blown forward by the fan.

Figure A-1. Antari Snow machine, and demonstration of foam snow

To pilot test this system, the machine was mounted to the hood of a plow truck and driven around the University of Minnesota area. The machine was set to run at full snow volume on the highest fan speed. Some results of this testing are pictured below in Figure A-2.

The volume of snow that the machine produced was less than adequate. Also, the fan was not powerful enough to blow the snow towards the windshield while driving above 15 miles per hour. Even with the predicted help of 2 or more machines, the snow quality and volume that would be produced would seem less than a flurry. Thus, the foam-snow machine was not considered adequate for our testing purposes.

Figure A-2. Foam-snow machine during pilot testing on the hood of a plow truck

APPENDIX B – TRACK TEST EXPERIMENTER INSTRUCTIONS

Instructions in plain font were to be read aloud to the participant.
Instructions that are Underlined indicate some action must be taken in addition to reading the instructions.
Instructions that are ***Underlined and Italics*** indicate that some action must be taken by the experimenter and should not be read aloud.

PreTest Instructions

1. Thank you for participating in our field operation testing and this track evaluation. Due to the lack of low-visibility weather conditions, we have brought you here to gather the necessary data we were not able to collect this winter.

2. First, please fill out this short background questionnaire.

3. Today you will be driving the Mn/ROAD track under different visibility conditions and with different assistive setups. It is very important to remember your first priority is safety. If at any time you need to stop or take a break, you may. The driving conditions we have simulated were intended to be difficult, and if you do not feel safe for any reason, notify the researchers. This means you can ignore the researcher instructions or the task requirements if you do not feel safe.

4. Before testing begins, you will practice driving the track in order to get familiar with the layout of the road. Though it seems like a simple track, there are many potentially dangerous sections of the road, especially when driving in our low light conditions. Since this is a pavement research facility, there are many expensive equipment boxes throughout the track. These will be shown to you so that you have a better idea of what is out there in the dark. During the experiment, the experimenters will be in radio contact with you at all times. Also, a car will be constantly watching you to make sure you stay safe and on the road.

5. The practice laps will also get you familiar with the experimental driving conditions you will be exposed to while driving. A good proportion of your driving will be under poor lighting conditions. You will have to be careful to stay on the road and drive in a safe manner. The driver assistive system from the field test will be available for you to use during portions of the test. The practice laps will re-familiarize you with these systems.

6. One thing the practice laps will not familiarize you with are obstacles on the road. During some of your experimental laps you will encounter an object in the path of your truck. When you first see the obstacle, signal a left turn as you turn away from it. The use of the turn signal as soon as you see the obstacle is important to us. This is the signal we will use later in the data to know when you saw the obstacle. Avoid the object as if it were a car stranded on the road. If you hit an obstacle, do not stop unless you feel it is unsafe to continue driving. For example, you should stop if the obstacle is caught on your truck, but not if you just knock it over.

7. During the experiment, you will be driving three laps at a time. Between each set of laps you will be given a few short questionnaires about the driving you just completed. Breaks will be given a few times during testing. When the track testing is complete, we will return here for a final briefing and questionnaire.

8. Now we will go out to the plow to begin the testing. Please use the restroom now if you need to.

Practice Circuit Instructions

Laps 1 & 2 – Track Familiarization

1. *Turn off the DAS and Loading Task.*

2. Please make yourself comfortable, you will be driving this truck for the next few hours. Also, if you need to get familiar with this particular cabin setup, do so now.

3. While driving, if you have any problems or need to contact the experimenters, use the radio. If you cannot reach them by the radio, or if you need to stop in the middle of a lap, turn on the "Front-Rear Strobes" light, the first switch in this row of lights.
   Point out and have them try the Front-Rear Strobes light.

4. Here is a map with some of the dangerous sections shown. *Hand driver the map*.
   [*see* Figure B-1. *Original map size was a full 8.5 x 11 page.*]

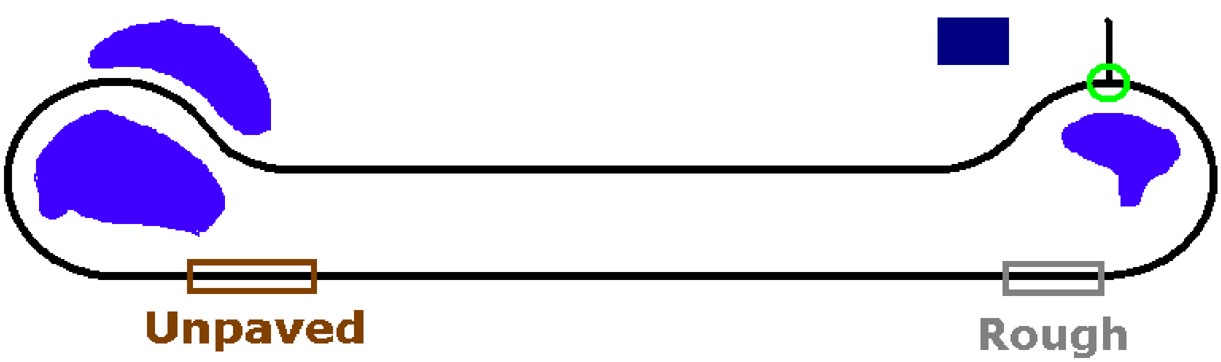


Figure B-1. Representational map of test track hazards shown to participants.

Notice that there is a rough section just after this first curve, and a large unpaved section at the end of the first straight. Also notice that that the track runs close to a few ponds. You will see these and other features during the drive.
Take back map once done looking at it.

5. While driving around the track do not ever exceed 35 mph. You will be asked to drive at particular speeds at certain times, but always drive at a speed you feel is safe. For these practice runs you are asked not to exceed 20 mph, so you can get a better feeling for your surroundings.

6. During these laps you will also see one of the obstacles I have mentioned before. I'll point it out as it comes into view, and when you first see it, turn on your left turn signal as you begin maneuvering around it.

7. Now As a warning to everyone around the truck, honk your horn before beginning to move. Please honk now.

8. Now proceed to drive the track clockwise, staying in the center, inside lane. Notice the different road surfaces as we go.
    a. Take careful note of the rough and unpaved sections of track, as well as frost heaves. These sections will be even less visible during the experiment and you will need to watch your speed when approaching them.
    Point out rough sections, especially the long one on straight 1, highway side of the track.
    b. Also take a look at the metal cabinets located next to the road throughout the track. These cabinets are the control centers for other Mn/ROAD research, and need to be avoided at all costs.
    Point out the boxes, especially those in the middle median and those on the western most side of the track.

9. After the second lap, stop at the access road.

10. Do you have any questions about driving the track?

Lap 3 – Loading Task

1. Now I will show you the additional task you will be doing while driving. While driving around the track, we ask that you complete the task as quickly and accurately as possible. *Start up the Loading Task.*

2. This is what you will see on the touch screen while driving. As you can see there are four circles, or lights, above four blue buttons. When you hear a tone, one of the lights will light up. As soon as you can, press the button underneath that light. After pressing any button, the light will turn off. Once the light turns off, that trial of the task is over and you may continue driving as normal. After a short pause, the task may begin again as indicated by another tone. Repeat this activity as long as you hear a tone.

3. But again, your first priority is to drive safely. If you do not feel safe, you may wait to respond to the task. Please then respond at the next safe opportunity.

4. As a specific safety concern, we want you to ignore this task while you are in the curves of this test track. You do NOT have to continue responding on the curves even though the task will continue to make tones. From the beginning of the turn until you are back on the straight-away you should ignore the task. As soon as you are back on the straight-away, hit the button underneath the lit circle to let us know you made it safely out of the turn.

5. Now we're going to drive a lap while performing the task to let you see how it works. For this practice run you are asked not to exceed 20 mph, so you can get a better feeling for your surroundings and the task.
   Please honk, then begin driving.

6. After the lap, stop at the access road.

11. Do you have any questions about driving the track or the task?

Lap 4 – Low Visibility

1. As I mentioned before, during the majority of the experiment you will be driving under simulated low-visibility conditions. We will now set up the truck for those conditions. For me to do this, I'll need you to get up for a moment so I can pull down the window shading. This will only take a minute.
   Maneuver blinders, pull down and flatten tinting.

2. *Have driver get back into truck.*

3. As you can see, it is a lot harder to see the road now than it was before. This low light condition will also make it even harder for you to see the frost heaves, equipment boxes, and rough unpaved sections of the track. Remember to pay attention to these hazard areas.

4. Now we're going to drive a lap in this low light condition. For this practice run you are asked not to exceed 20 mph, so you can get a better feeling for your surroundings and the low lighting.
   Please honk, then begin driving.

5. *During lap, place WL measures in clipboard.*

6. After the lap, stop at the access road.

7. Do you have any questions about driving the track under these conditions?

8. After each set of three laps, you will be asked to park the plow here so you can fill out a few questionnaires regarding the laps you just drove. These questionnaires are related to the amount of effort it took you to complete the last set of laps. I will now go through some of those questionnaires with you.

9. *Hand driver the clipboard with the three workload measures, TLX, RSME, Cooper-Harper.*

   The first measure is titled Mental Workload Ratings. It shows you seven different types of effort. You are asked to think about how you felt during the laps you just completed, then place a vertical line to indicate how much workload you felt in of the following:
   a. Mental Demand, or how much thinking, deciding, calculating, remembering did you need to do?

    b. Physical Demand, or how much physical activity was required?
    c. Visual Demand, or how much looking, searching, visual activity was required?
    d. Time Pressure, did you feel under pressure to complete the driving task in the time available?
    e. Performance, or how satisfied were you with your level of performance?
    f. Effort, or how hard did you have to work?
    g. Frustration Level, or how insecure, discouraged, irritated, stressed, and annoyed were you during the drive?

   You are to place a line on the scale to indicate how much of that particular dimension of effort you felt.
   Please answer this questionnaire now.
   Check answers to make sure they're doing it correctly.

10. The next page is titled Rating Scale of Mental Effort. It shows you a single line with a range from 0 to 150. On this line you are to make a line to show how much effort it took for you to complete the task you've just finished. You may use the labels on this scale to help locate your own rating.
    Please answer this questionnaire now.
    Check answer to make sure they're doing it correctly.

11. The third page shows you a flow chart, starting in the bottom left hand corner. You are to read the question in this box and, depending on your answer, follow the arrows either up or to the right. The questions will lead you to rate the difficulty level and a workload rating for the laps you just completed.
    a. For example, the first question asks, "Although errors may be large or frequent, can task be accomplished most of the time?"
    b. If your answer is Yes, in other words that the task can be completed most of the time, you would follow the Yes arrow upwards to the box that reads, "Are errors small and inconsequential?"
    c. If your answer then is No, in other words that the errors are not small", you would follow the No arrow to the right, reading the boxes that follow.
    d. On the right side of that line, there are three boxes with numbers under the column labeled Rating. Your final response will be to circle one of those numbers, indicating how difficult the task was.

    Please read through the different paths and then answer this questionnaire now.
    Check answer to make sure they're doing it correctly.

12. *Take back clipboard.*

13. We will now set up the truck up for normal conditions again. For me to do this, I'll again need you to get up for a moment so I can pull up the window shading. This will only take a minute.
    Un-maneuver blinders, roll up tinting.

14. *Have driver get back into truck.*

Lap 5 DAS-3M Transition

1. During some of the laps, you will be allowed to use the driving assistive systems from this winter's field-testing. During this testing you will be using the heads up Display, vibrating seat, and audio warnings from the Driving Assistive System. However, unlike the field-testing, you will not be able to shut off any parts of the system.

2. Please lower and adjust the heads up display so that it is in a comfortable viewing position.
   Turn on DAS.

3. At times during the field test, the system may have turned off for a short time before resuming its GPS fix. During this time, magnetic tape installed on parts of the road allows the system to continue telling you were your truck is in the lane. The next lap we drive will simulate that condition here.
   Turn on 3M-Transition.

4. Now we're going to drive a lap while using the Driver Assistive System and 3M magnetic tape as a backup. For this practice run you are asked not to exceed 20 mph, so you can get a better feeling for your surroundings.
   Please honk, then begin driving.

5. After the lap, stop at the access road.

6. Do you have any questions about driving the track under these conditions?

7. Again, after each set of three laps, you will be asked to park the plow here so you can fill out these workload questionnaires which you filled out a few laps ago.
   Hand driver workload, usability, and trust measures on clipboard.
   Please fill out these questionnaires now.

8. Below those are some new questionnaires related to your opinions of the systems you just used. I will now go through these questionnaires with you.

9. The first measure is titled Driver Assistive System Usability. It shows you rows of words with opposite meanings. You are asked to rate your opinion for each descriptive word by marking the box that best describes how close you feel to either of the words.
   a. For example, in the gray box are listed the words easy and difficult. If you felt the system was very easy to use, you would mark the box closest to the word easy.
   b. Below that are listed the words Simple and Confusing. If you thought the system was a little bit confusing, you would mark the fourth box in that row.

   Please answer this questionnaire now.
   Check answers to make sure they're doing it correctly.

10. The next two pages are titled System Trust Questionnaire. They show you some statements relating to your opinion of the assistive system you just used. Underneath each statement is a line for you to indicate how much you agree or disagree with the statement. Make a mark on the line to indicate your agreement.
    Please answer both pages of this questionnaire now.
    Once both pages are completed, check answers and take the clipboard from the driver.

11. After completing these surveys, I will also be asking you questions on your opinion of the system you just used. We won't go through these questions right now, just know that I'll ask you these questions verbally here in the truck and I will record your responses for you like an interview.

12. The practice laps are now over. Do you have any other questions about the study right now?

13. Before we begin testing, you may now take a 5 to 10 minute break.

Experimental Circuit Instructions

Overall Instructions

1. *Set up the first condition.*

2. *Have the driver get back into the truck.*

3. Please make yourself comfortable in the truck once again.

4. Now we will begin the experimental conditions. Again, you will be driving three laps at a time, starting and ending here at the access road. Once the plow is set up, do not begin until I tell you over the radio to begin. I will also tell you when you are approaching the point on your third lap.

5. At all times while driving, John, you, [who's at station], and myself will always be in radio contact with you. John will be following you in his car to make sure you don't run into any trouble. If he thinks you are in immediate danger, he will signal you with the radio.

6. There is a possibility that we may loose our GPS signal and not be able to use the systems for a little while. If it appears that you have lost the GPS signal **for an entire lap**, notify us by radio and we will instruct you on what to do.

7. While driving, you will be asked to maintain different speeds depending on which direction you are driving. In the lane closest to the highway, the one traveling away from the Mn/ROAD building, you are to drive at or under 25 mph. However if you feel you need to drive slower to be safe, please do so.

8. While driving in the lane further from the highway, the one traveling back towards the building on your return leg, you are to drive at any speed that is most comfortable to you. However, do not drive above 35 mph. Please drive at a speed which allows you to maintain control of your truck under the conditions presented to you.

9. Finally, remember that while driving you will come upon objects in the path of your truck. When you first see the obstacle, signal a left turn so that we know you have seen it. Then proceed to avoid the object as if it were a car stranded on the road. If you hit an obstacle, do not stop unless you feel it is unsafe to continue driving. For example, you should stop if the obstacle is caught on your truck.

10. Any other questions?

11. Remember safety is first, and if you do not feel safe while driving under the current conditions to just slow down, radio us, or stop. Now wait here and I'll tell you over the radio when to begin.

12. *Get to obstacles, then radio driver to begin.*

12. *Note start time of this circuit.*

13. *Place obstacle in road halfway over fog line during the appropriate lap. Then walk over to the far side of the road and watch to see if the truck hits it.*

14. *After truck passes, remove obstacle and replace into side of road.*

15. *Note hit/miss.*

16. *Have John pick you up on the third lap, then radio driver that it's time to stop at the access road*

17. *Note end time of this circuit.*

18. *Administer workload measures, trust surveys and interviews.*

19. *After completing 2 circuits, give another 10-15 minute break.*
    After completing 4 circuits, return to clubhouse.

20. *Set up next condition, go back to #8*

21. *Give final interview and survey.*

22. Thank you for participating in tonight's and this winter's testing of this system. If you have any other questions of the system or the results of this testing, please contact me or John.

APPENDIX C – 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

To determine the operators' views of how useful and satisfying the system was to them, the above questions will be given to the operators after each LV DAS and LV DAS Transition circuit. Operators will be asked to rate their agreement with each of these sets of descriptive items.

Operators will be instructed to mark the box that best describes their experience with the system in question. Responses will be scored and then Usefulness and Satisfying scores will be calculated separately for the DAS and 3M systems (during transition circuit).

APPENDIX D- TRUST QUESTIONNAIRE

The System Trust Questionnaire asked the operators their opinion of the system they just used. Operators were asked to indicate on a continuum how much they agree or disagree with the following statements:

1. The performance of the system enhanced my driving safety.
2. I am familiar with the operation of the system.
3. I trust the system.
4. The system is reliable.
5. The system is dependable.
6. I have confidence in the system.
7. The system has integrity.
8. I am comfortable with the intent of the system.
9. I am confident in my ability to drive the truck safely without the system.

Eight of these nine statements were from the original scale used by McGehee and Raby (2002) and developed at the University of Iowa, using classifications from Lee and Moray (1992). We have added statement number 6 for this study.

The continuums are labeled on a range from "0 = Strongly Disagree", to a midpoint marked "50", to a far pole marked "100 = Strongly Agree". Scores were derived based on their relative distance to these numerical poles.

APPENDIX E – INTERVIEW QUESTIONNAIRES

The experimenter will pose the interview questions to the operators aloud. 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 will be given to the operators to refer to while answering these questions.

In the lists 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

There are separate sets of interview questions following the DAS and TRAN circuits. Each of these asks questions comparing that particular system to driving without aid. There is also a third set of questions that will be asked at the end of testing that ask operators to compare using the DAS to using the 3M system.

Below is the list of questions asked after the DAS condition followed by the questions asked to compare the two systems. The questions asked after the TRAN condition have not been included, since they are exactly the same as the DAS questions, only pertaining to this other condition.

DAS Condition Interview Questions

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.

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.

5. The DAS provided me with reliable information.
6. The DAS was useful in poor visibility.
7. I had confidence that the DAS would help me maintain my lane position.
8. 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)
9. Remembering how to use the DAS was difficult.

   a. What have you learned from using the DAS that you should have been told before using it? (open ended)

10. Using the DAS made me a safer driver.
    a. In what ways? (open ended)
11. 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)
12. What parts of the current DAS should be removed? (open ended)
    a. What things would you like added to improve the DAS? (open ended)
13. It was easier for me to drive while using the DAS.
    a. Why?
14. I was satisfied with the overall performance of the DAS.
15. Would you like to have the DAS permanently installed in your truck? (yes/no)
16. Would you recommend that Mn/DOT install the DAS in all plows? (yes/no)
    a. Please explain your recommendations… (open ended)

End Interview Questions

You have now completed the track testing and are familiar with using the Driving Assistive System in low-visibility conditions similar to those of a whiteout. The following questions ask your opinion of the system from tonight's testing ONLY.
When I say "DAS" I mean the Driving Assistive System consisting of the HUD, Audio, and Seat warnings.
When I say "Tape backup system" I mean the HUD display that replaced the DAS during the simulated poor satellite fix condition.
Indicate the number that tells how much you agree or disagree with each statement.

I. DAS

1. Which of the following DAS warnings could you see yourself using on a regular basis? (HUD, Audio Warnings, Vibrating Seat Warnings)
2. I was easily able to understand the HUD display for the DAS.
3. I liked the HUD display for the DAS.
4. If you could, what would you change about the HUD component? (open ended)
5. The seat vibration was useful in helping me maintain lane position.
6. I considered the seat vibrations annoying.
7. If you could, what would you change about the seat vibration component? (open ended)
8. The audio warning was useful in helping me maintain lane position.
9. I considered the audio warnings annoying.
10. If you could, what would you change about the audio warning component?
11. I imagine using the DAS for 12 hours would be annoying.
12. If so, what elements would be annoying?
13. The DAS is reliable.
14. The DAS made me more aware of my lane position.
15. The DAS helped me spend less time looking for obstacles in the roadway.
16. The DAS allowed me to spend more time doing other tasks (for example, the loading task).
17. Did the DAS ever prompt you to make a wrong action or an error in judgment? (yes/no)
    a. If Yes, explain: (open ended)

18. The warnings provided by the DAS enabled me to respond quickly to a lane departure.
19. Compared to not driving with the DAS, I felt having it enhanced my ability to maintain lane position while driving on straights.
20. Compared to not driving with the DAS, I felt having it enhanced my ability to maintain lane position while driving on curves.
21. The system was intuitive to me.

II. Tape Backup System

22. I was easily able to understand the HUD display for the Tape backup system.
23. I liked the HUD display for the Tape backup system.
24. The Tape backup system in the HUD was helpful to maintaining lane position.
25. I felt able to maintain control during the transitioning between the DAS and Tape HUD systems.
26. I felt safe during the transitioning between the DAS and Tape HUD systems.
27. The transition between the full DAS and Tape lane detection displays in the HUD was confusing and distracting.
28. Would you prefer to see the Tape backup system on the HUD when the GPS looses its fix, or would you prefer to see nothing at all? (3M/Nothing)
29. Would you prefer the Tape Backup System to warn you though the HUD, seat, audio, or some other method? (HUD, Seat, Audio, Other)
    a. Explain your recommendation: (open ended)
30. Would you like to see any implementation of the Tape Backup System installed by itself in your truck? (yes/no)
    a. Explain your recommendation: (open ended)

APPENDIX F – FINAL SURVEY

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

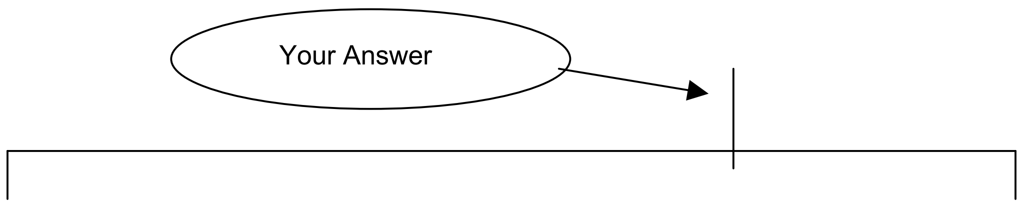
Final Survey

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?

____

____

____

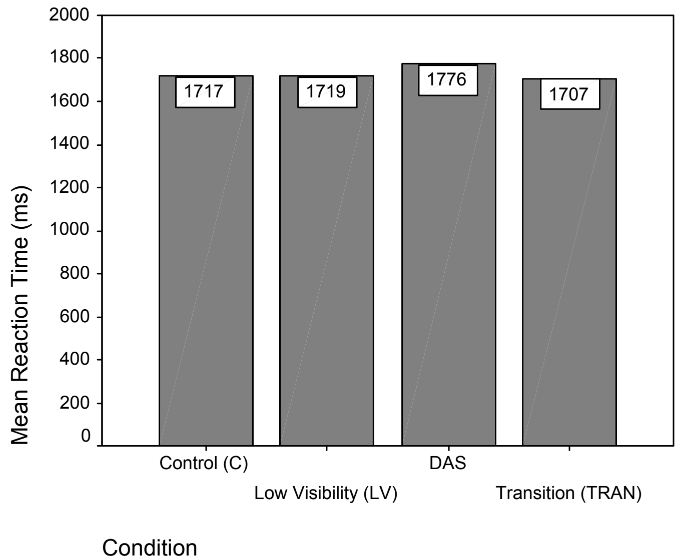
____

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

APPENDIX G – LOADING TASK PERFORMANCE RESULTS

Loading task performance was measured in terms of the driver's RT to pressing the task button and the percentage of correctly answered items. For RT, times from both correct and incorrect responses were combined over both straights. The mean RT was calculated for each condition from these scores. No time was recorded if the driver did not respond to the task.

The loading task performance results are shown in Figure G-1.



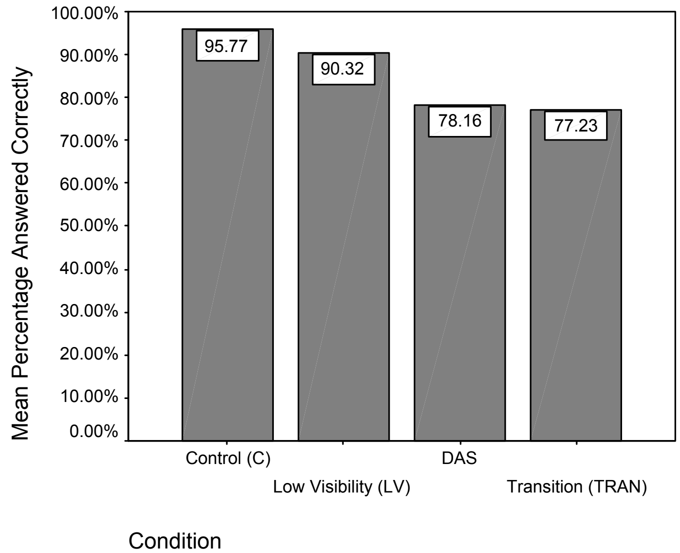
		Wilcoxon Signed Ranks Test		
Analysis	Comparisons	Z	*p*	Power
Effects of LV	C - LV	0.14	0.889	0.050
System Effects	LV - DAS	0.11	0.917	0.061
	LV - TRAN	0.68	0.499	0.087
Baseline Comparisons	C - DAS	0.94	0.345	0.064
	C - TRAN	0.34	0.735	0.051
Effects of TRAN	DAS - TRAN	0.73	0.463	0.102

Figure G-1. Graph and Wilcoxon Signed Ranks Tests of loading task performance mean RT

There were no significant differences for any of these RT comparisons. We predicted that drivers would be less able to quickly respond during the DAS and TRAN conditions, but this was not shown in their RT to the loading task. This may suggest that drivers gave the task minimal importance throughout the testing and therefore they responded in a similar manner during all of the conditions.

As is the case with driving in general, the nature of the assistive technologies used in this study allow drivers to look away for moments at a time to do other tasks. However, the addition of these tasks to the already present driving task did not cause drivers to slow their RT.

Loading task performance was also analyzed in terms of the percentage of correct responses out of all possible trials during a condition. These results are shown in Figure G-2.



Analysis	Comparisons	Wilcoxon Signed Ranks Test Z	*p*	Power
Effects of LV	C - LV	0.84	0.398	0.100
System Effects	LV - DAS	1.57	0.116	0.337
	LV - TRAN	2.24	0.025 *	0.410
Baseline Comparisons	C - DAS	1.18	0.237	0.209
	C - TRAN	1.68	0.093 '	0.227
Effects of TRAN	DAS - TRAN	0.31	0.753	0.063

' Marginally significant
* Significant at .05 level

Figure G-2. Graph and Wilcoxon Signed Ranks Tests for percentage of correct responses on the loading task

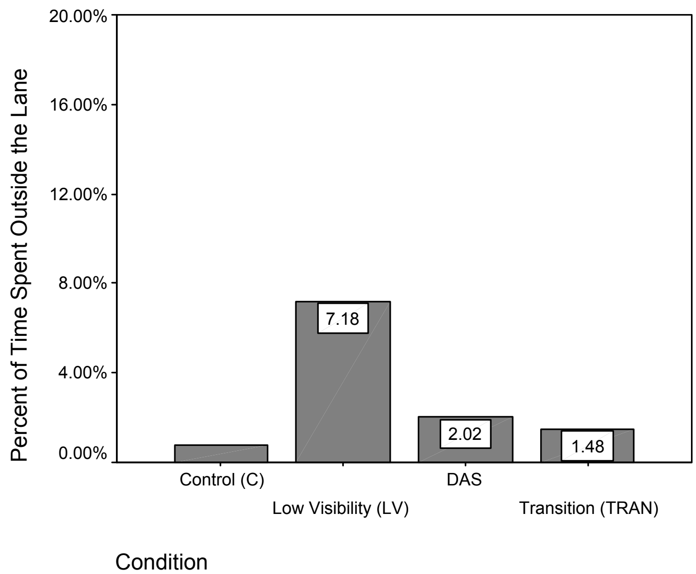
Again, the number of correct and incorrect responses (including those trials not answered or ignored) was combined over both straights. The percentage of correctly answered trials was calculated for each condition from these scores.

Results showed that there were no significant differences between conditions with the exception that drivers answered fewer questions correctly in the TRAN condition than in the LV condition. Overall, the data suggest a trend for the drivers in the assistive system conditions (DAS & TRAN) to have a lower percentage of correctly answered trials than the unassisted conditions (C & LV). This is to be expected, since the drivers may have chosen to ignore the task while dealing with the more taxing LV conditions (LV, DAS, & TRAN) and when having to interpret additional information from the two systems (DAS & TRAN conditions).

APPENDIX H – LANE DEPARTURE RESULTS, STRAIGHT 2 AND CURVES

Straight 2

The percentage of time spent outside the lane boundaries on Straight 1, while asked to drive at a comfortable speed, is presented in Figure H-1.

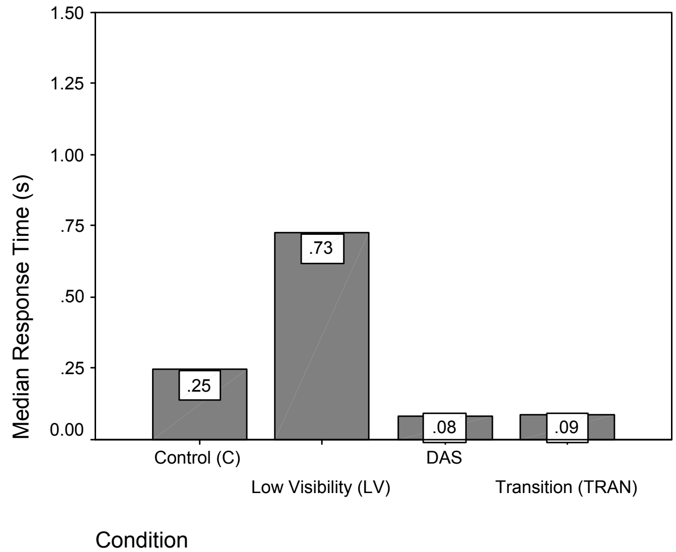


		Wilcoxon Signed Ranks Test		
Analysis	Comparisons	Z	*p*	Power
Effects of LV	C - LV	0.37	0.715	0.117
System Effects	LV - DAS	0.14	0.893	0.101
	LV - TRAN	0.94	0.345	0.107
Baseline Comparisons	C - DAS	0.94	0.345	0.117
	C - TRAN	0.41	0.686	0.071
Effects of TRAN	DAS - TRAN	1.10	0.273	0.177

Figure H-1. Graph and Wilcoxon Signed Ranks Tests for the percentage of time spent outside of the lane on Straight 2

There were no differences between the conditions for the percentage of time spent outside of the lane. The graph suggests a trend where the system-assisted conditions (DAS & TRAN) spent less time outside the lane than the LV condition, which is on par with the C conditions of clear visibility.

The median amount of time it took drivers to recover from lane departures is presented in Figure H-2.

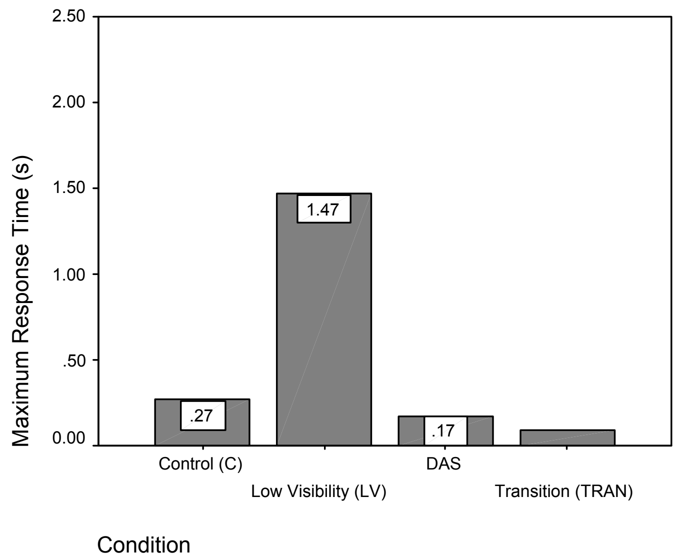


Analysis	Comparisons	Wilcoxon Signed Ranks Test Z	*p*	Power
Effects of LV	C - LV	1.10	0.273	0.140
System Effects	LV - DAS	1.21	0.225	0.223
	LV - TRAN	1.08	0.279	0.212
Baseline Comparisons	C - DAS	0.41	0.686	0.102
	C - TRAN	0.41	0.686	0.097
Effects of TRAN	DAS - TRAN	0.37	0.713	0.050

Figure H-2. Graph and Wilcoxon Signed Ranks Tests for median response time to recover from a lane boundary departure on Straight 2

There were no differences between any of the conditions for the median response time, though the DAS and TRAN conditions appear to have lower median response times than the LV and possibly the C conditions.

The maximum amount of time it took drivers to recover from lane departures is presented in Figure H-3.



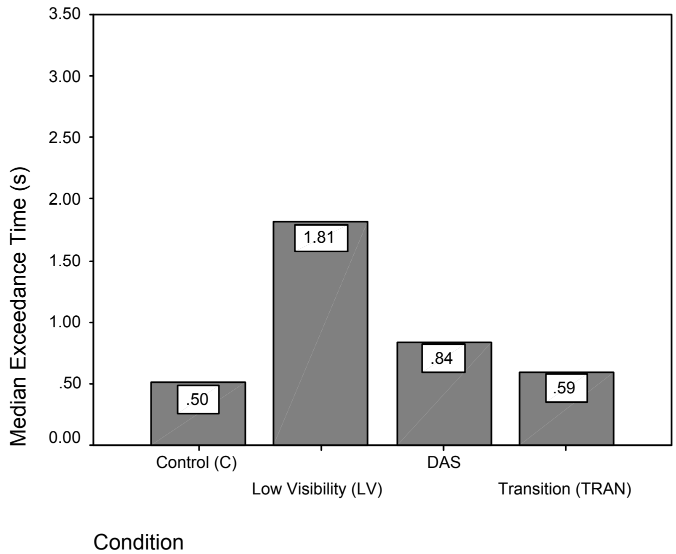
Analysis	Comparisons	Wilcoxon Signed Ranks Test Z	p	Power
Effects of LV	C - LV	1.10	0.273	0.125
System Effects	LV - DAS	0.94	0.345	0.154
	LV - TRAN	1.08	0.279	0.160
Baseline Comparisons	C - DAS	0.41	0.684	0.064
	C - TRAN	0.41	0.686	0.108
Effects of TRAN	DAS - TRAN	1.84	0.066 '	0.315

' Marginally Significant

Figure H-3. Graph and Wilcoxon Signed Ranks Tests for maximum response time to recover from a lane boundary departure on Straight 2

There were no significant differences between any of the conditions for the median response time, though the DAS and TRAN conditions appear to have lower maximum response times than the LV condition, on par with the C condition.

The median duration of lane departures is presented in Figure H-4.

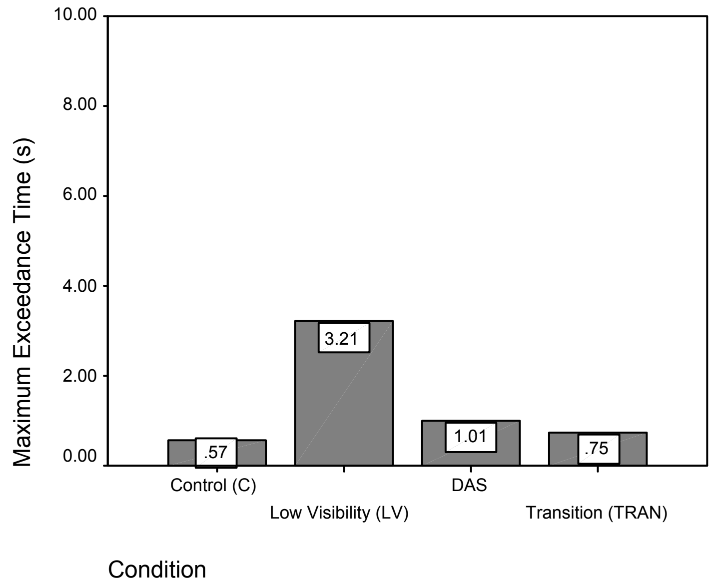


Analysis	Comparisons	Wilcoxon Signed Ranks Test Z	*p*	Power
Effects of LV	C - LV	0.73	0.465	0.123
System Effects	LV - DAS	0.41	0.686	0.095
	LV - TRAN	1.21	0.225	0.137
Baseline Comparisons	C - DAS	0.41	0.686	0.071
	C - TRAN	0.14	0.893	0.051
Effects of TRAN	DAS - TRAN	1.10	0.273	0.167

Figure H-4. Graph and Wilcoxon Signed Ranks Tests for median time duration of lane boundary departures on Straight 2

There were no differences between any of the conditions for the median duration of boundary departures, though the DAS and TRAN conditions appear to have lower median exceedance times than the LV condition.

The median duration of lane departures is presented in Figure H-5.



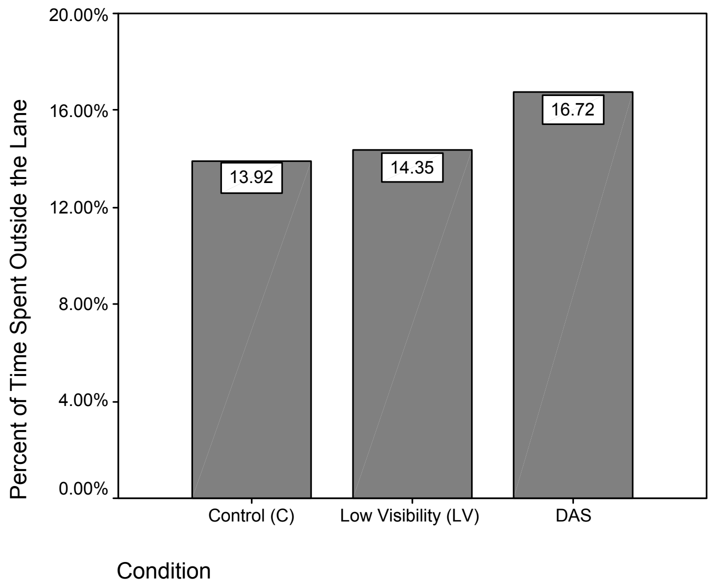
		Wilcoxon Signed Ranks Test		
Analysis	Comparisons	Z	*p*	Power
Effects of LV	C - LV	0.37	0.715	0.119
System Effects	LV - DAS	0.27	0.786	0.105
	LV - TRAN	0.94	0.345	0.118
Baseline Comparisons	C - DAS	0.41	0.686	0.078
	C - TRAN	0.41	0.686	0.055
Effects of TRAN	DAS - TRAN	0.73	0.465	0.130

Figure H-5. Graph and Wilcoxon Signed Ranks Tests for maximum time duration of lane boundary departures on Straight 2

There were no differences between any of the conditions for the maximum duration of boundary departures, though once again it appears that the assisted conditions (DAS & TRAN) have lower maximum exceedance times than the LV condition.

Curves

The percentage of time spent outside the lane boundaries on the Curves is presented in Figure H-6.

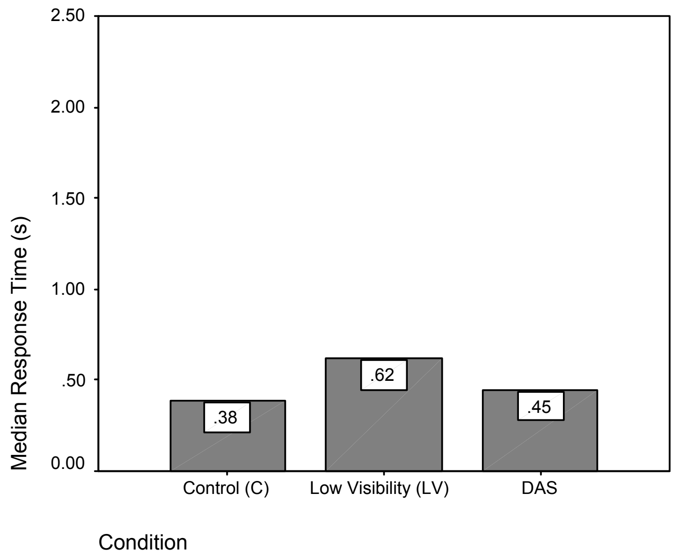


		Wilcoxon Signed Ranks Test		
Analysis	Comparisons	Z	*p*	Power
Effects of LV	C - LV	0.14	0.893	0.052
System Effect	LV - DAS	0.41	0.686	0.062
Baseline Comparison	C - DAS	0.67	0.500	0.079

Figure H-6. Graph and Wilcoxon Signed Ranks Tests for the percentage of time spent outside of the lane on Curves

There were no differences between the conditions for the percentage of time spent outside of the lane.

The median amount of time it took drivers to recover from lane departures is presented in Figure H-7.

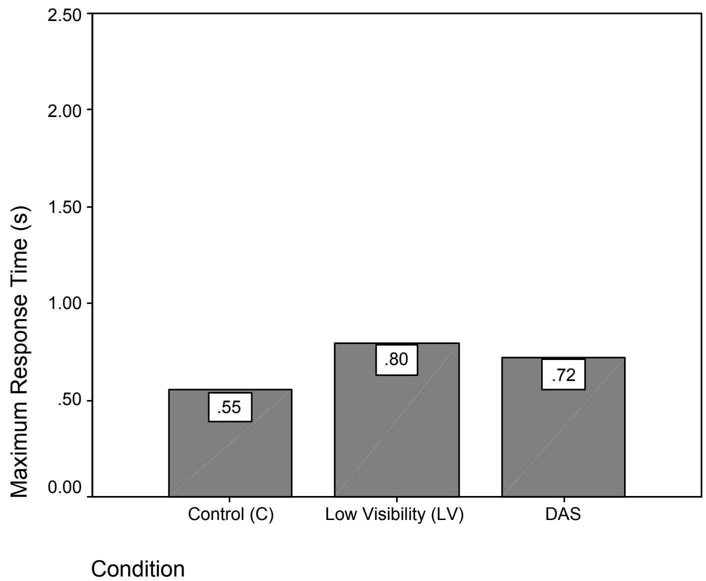


		Wilcoxon Signed Ranks Test		
Analysis	Comparisons	Z	*p*	Power
Effects of LV	C - LV	0.94	0.345	0.145
System Effect	LV - DAS	0.67	0.500	0.084
Baseline Comparison	C - DAS	0.41	0.686	0.060

Figure H-7. Graph and Wilcoxon Signed Ranks Tests for median response time to recover from a lane boundary departure on Curves

There were no differences between any of the conditions for the median response time.

The maximum amount of time it took drivers to recover from lane departures is presented in Figure H-8.

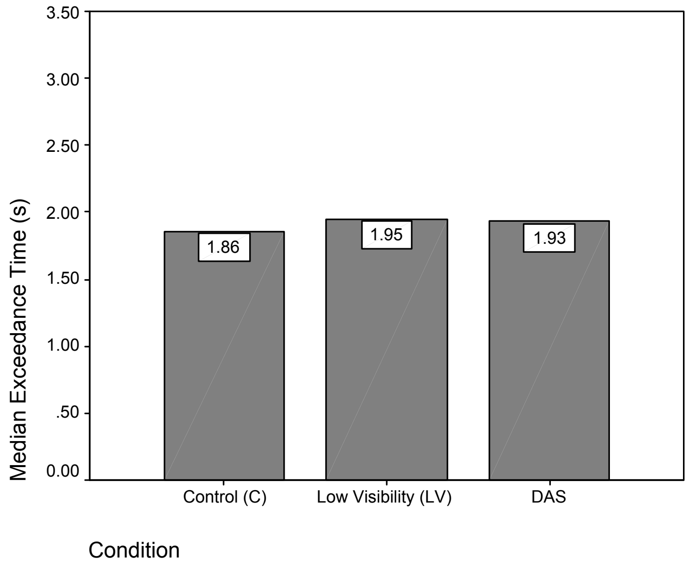


		Wilcoxon Signed Ranks Test		
Analysis	Comparisons	Z	*p*	Power
Effects of LV	C - LV	1.21	0.225	0.139
System Effect	LV - DAS	0.14	0.893	0.054
Baseline Comparison	C - DAS	0.67	0.500	0.096

Figure H-8. Graph and Wilcoxon Signed Ranks Tests for maximum response time to recover from a lane boundary departure on Curves

There were no significant differences between any of the conditions for the median response time.

The median duration of lane departures is presented in Figure H-9.

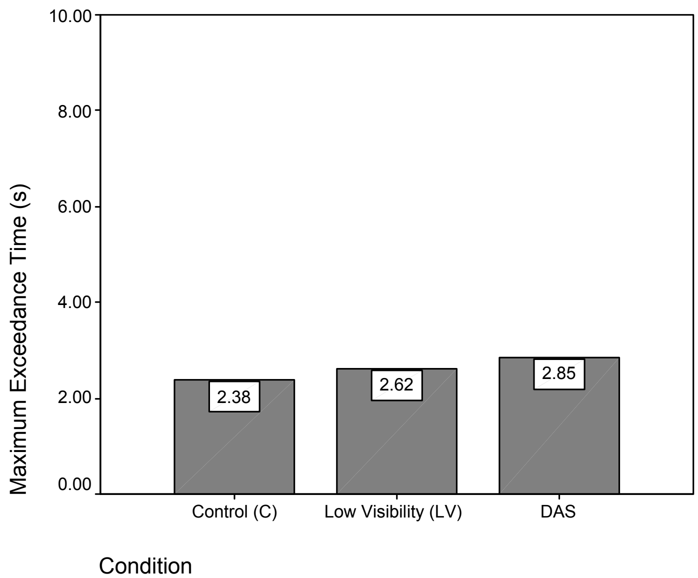


Analysis	Comparisons	Wilcoxon Signed Ranks Test Z	 *p*	 Power
Effects of LV	C - LV	0.41	0.686	0.056
System Effect	LV - DAS	0.14	0.893	0.050
Baseline Comparison	C - DAS	0.41	0.686	0.053

Figure H-9. Graph and Wilcoxon Signed Ranks Tests for median time duration of lane boundary departures on Curves

There were no differences between any of the conditions for the median duration of boundary departures.

The maximum duration of lane departures is presented in Figure H-10.



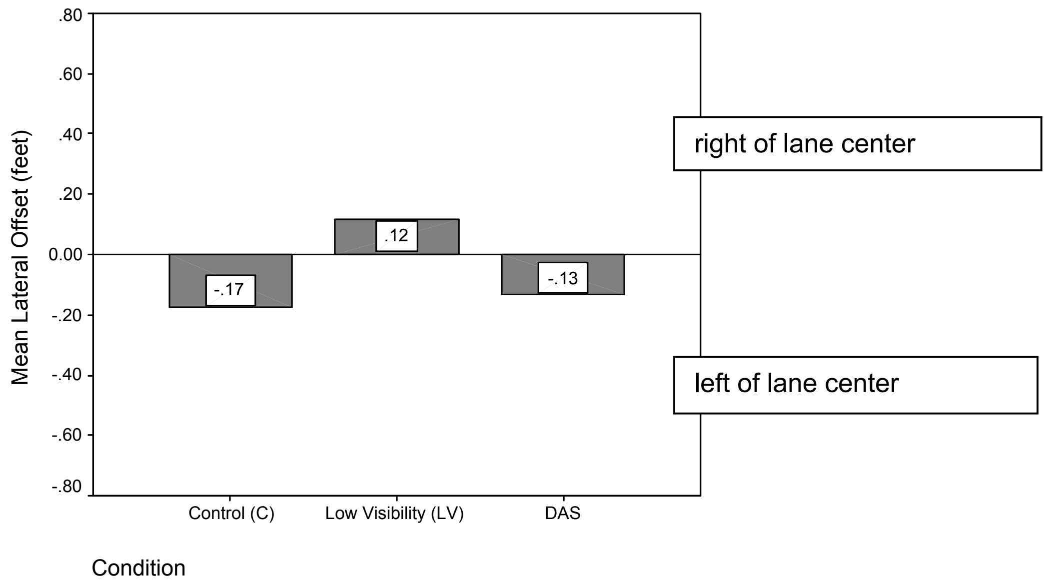
		Wilcoxon Signed Ranks Test		
Analysis	Comparisons	Z	*p*	Power
Effects of LV	C - LV	0.54	0.588	0.070
System Effect	LV - DAS	0.41	0.686	0.056
Baseline Comparison	C - DAS	0.67	0.500	0.093

Figure H-10. Graph and Wilcoxon Signed Ranks Tests for maximum time duration of lane boundary departures on Curves

There were no differences between any of the conditions for the maximum duration of boundary departures.

APPENDIX I – LANE POSITION RESULTS, CURVES

Figure I-1 presents the mean lane position during the Curves, while drivers were instructed to maintain a speed at which they felt comfortable.



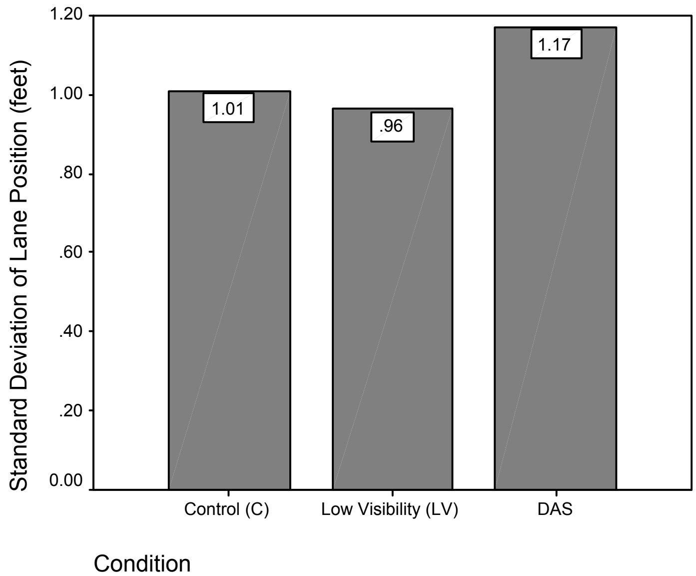
		Wilcoxon Signed Ranks Test		
Analysis	Comparisons	Z	*p*	Power
Effects of LV	C - LV	1.75	0.080 '	0.346
System Effect	LV - DAS	1.21	0.225	0.156
Baseline Comparison	C - DAS	0.41	0.686	0.054

' Marginally Significant

Figure I-1. Graph and Wilcoxon Signed Ranks Tests for mean lane position on Curves

There were no significant differences between the three conditions during the curves for mean lane position.

Variation in lane position for the curves is presented in Figure I-2.

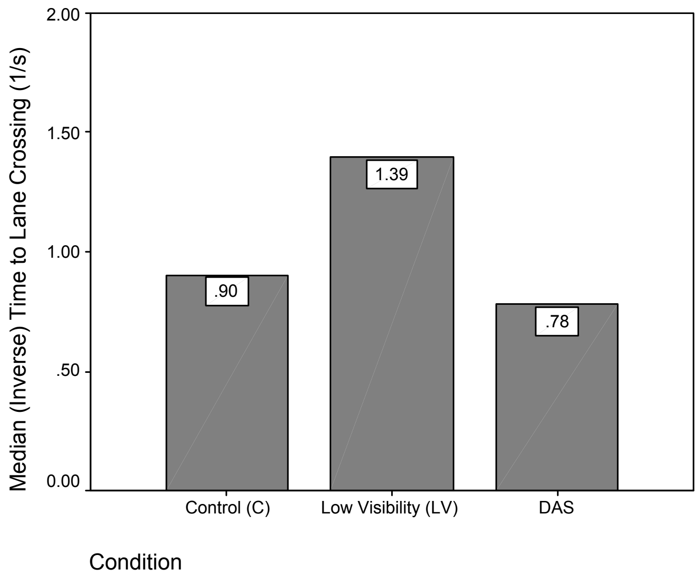


Analysis	Comparisons	Wilcoxon Signed Ranks Test Z	*p*	Power
Effects of LV	C - LV	0.41	0.686	0.085
System Effect	LV - DAS	0.67	0.500	0.113
Baseline Comparison	C - DAS	0.41	0.686	0.115

Figure I-2. Graph and Wilcoxon Signed Ranks Tests for standard deviation (variation) of lane position on Curves

Again, there were no differences in the drivers' variation in lane position during the curves.

Figure I-3 presents the median inverse of time-to-line crossing (1/TLC) during the Curves. Again, based on the inverse of TLC, larger values represent a shorter time-based safety margin.

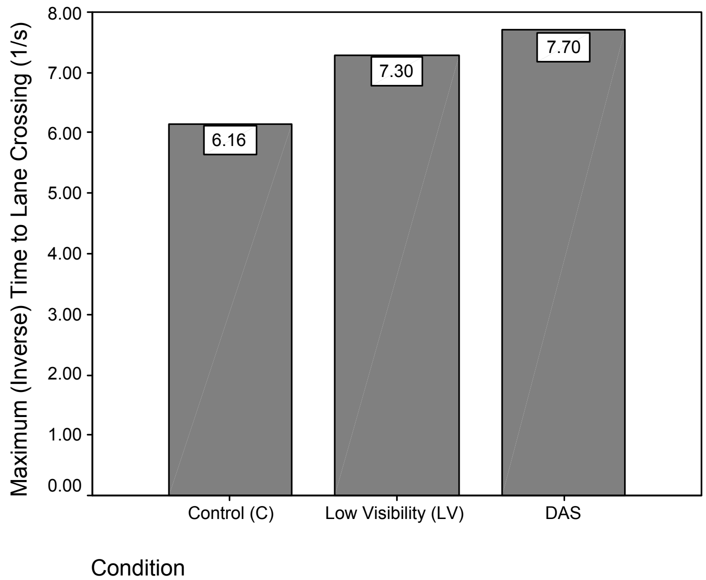


Analysis	Comparisons	Wilcoxon Signed Ranks Test Z	*p*	Power
Effects of LV	C - LV	1.21	0.225	0.233
System Effect	LV - DAS	0.94	0.345	0.189
Baseline Comparison	C - DAS	0.41	0.686	0.073

Figure I-3. Graph and Wilcoxon Signed Ranks Tests for median inverse of time-to-line crossing (1/TLC) on Curves (excluding lane departures)

There were no differences between the conditions for median 1/TLC while driving the Curves.

Figure I-4 presents the maximum (85th percentile) inverse of time-to-line crossing results.



		Wilcoxon Signed Ranks Test		
Analysis	Comparisons	Z	*p*	Power
Effects of LV	C - LV	1.21	0.225	0.095
System Effect	LV - DAS	0.14	0.893	0.051
Baseline Comparison	C - DAS	0.14	0.893	0.078

Figure I-4. Graph and Wilcoxon Signed Ranks Tests for maximum inverse of time-to-line crossing (1/TLC) on curves (excluding lane departures)

Consistent with the two Straights, there were no significant differences between the comparisons for maximum 1/TLC on the curves.

Appendix J – Responses to Open-Ended Interview Questions

Specific results from the open-ended interview questions summarized in the results have been placed in tables below.

DAS and TRAN Interviews

If there was a follow up question to one of the preceding scaled questions, subjective comments were summarized and separated by DAS and TRAN conditions. They were also separated by whether they were positive or negative in nature. Positive summaries and comments are preceded by a plus sign ("+"), and negative ones are preceded by a minus sign ("-"). Repeated comments were tallied and following each comment is the percentage of total drivers who gave this response. This percentage is out of 8 total drivers interviewed for that condition; 9 drivers have input for the open-ended questions, but 2 of the drivers did not complete both the DAS and TRAN conditions. One completed only the DAS and the other completed only the TRAN condition, leaving 8 drivers' inputs for these questions.

Safety

"In what ways did using the DAS make you a safer driver?"

DAS	+	Confidence in lane position, tells me when I go out of my lane.	38% (3/8)
	+	Can't see Boxes normally until on them so HUD helps. Didn't see obstacle visually but saw it with the radar.	13% (1/8)
	+	Made me more alert, I paid more attention when things are flashing on the HUD	13% (1/8)
	+	Helped on curves	13% (1/8)
	-	I have confidence in myself to be a safe driver; I don't feel that I need the system.	25% (2/8)
	-	I don't fully trust it yet.	13% (1/8)
TRAN	+	Confidence in lane position, tells me when I go out of my lane.	38% (3/8)
	+	Radar helped me see obstacles.	13% (1/8)
	+	When I hit the gravel section, I relied on the DAS 100%. I had no idea, I couldn't see anything.	13% (1/8)
	+	It made me more alert, helped me pay attention more.	13% (1/8)
	-	The screen wouldn't stay in place, kept having to adjust it.	13% (1/8)
	-	Didn't trust, especially in the curves.	13% (1/8)

"Why did you find it easier/more difficult to drive while using the DAS?"

DAS	+	Could tell where the road is ahead, know what lane I'm in.	50% (4/8)
	+	Seeing obstacles in the radar	13% (1/8)
	-	Hard to navigate on curves.	25% (2/8)
	-	I don't like looking through the combiner, it gives me a headache.	13% (1/8)
	-	I have to concentrate more when system is on	13% (1/8)
TRAN	+	Helped me stay on my side of the road and see ahead	50% (4/8)
	+	Seeing obstacles in the radar	13% (1/8)
	-	I didn't put trust into 100%. Still relying on own ability, makes me uncomfortable	38% (3/8)
	-	Hard to navigate on curves	25% (2/8)
	-	No confidence in the arrow	13% (1/8)

Acceptance - Trust

"If you had trouble trusting the DAS, what were your reasons for this?"

DAS	+	n.a.	
	-	Looked under and around screen to get bearings and make sure screen was lined up and truthful	25% (2/8)
	-	Was most unsure on curves, since I couldn't see ahead	25% (2/8)
	-	Would rather be looking through windshield than HUD - trust myself more than HUD, I didn't like the lack of depth perception	13% (1/8)
TRAN	+	n.a.	
	-	Getting the HUD (Combiner) lined up	13% (1/8)
	-	The HUD didn't show much ahead of you on curves	13% (1/8)
	-	The Tape system was way too sensitive, kept bouncing back and fourth and incorrectly that I was far over in the lane.	13% (1/8)

"Would you like to have the DAS permanently installed in your truck?" (yes/no)

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

w/ Transitions	Yes	No
Eden Prairie	0	2
Shakopee	1	3
Hutchinson	2	0
Total	3	5

"Please explain these installation recommendations…"

DAS	+	All plows in areas with a high likelihood of winds. Not in urban areas.	38% (3/8)
	+	Would add to safety	13% (1/8)
	-	They're more work - Adds to already tough task	13% (1/8)
	-	Not as it is now, only if it was made rock solid (components and functioning)	13% (1/8)
	-	Too expensive	13% (1/8)
TRAN	+	All plows in areas with a high likelihood of winds. Not in urban areas.	63% (5/8)
	-	Hard to tell distances when coming upon obstacles in Radar, didn't understand changes in color.	25% (2/8)

Reliability

“What was most useful to you/what would be your ideal configuration of the DAS?“

DAS	+	Haptic seat and HUD	50% (4/8)
	+	HUD	38% (3/8)
	+	Haptic seat	13% (1/8)
	-	n.a.	
TRAN	+	Haptic seat and HUD	50% (4/8)
	+	HUD	25% (2/8)
	+	Haptic Seat	25% (2/8)
	-	n.a.	

“What parts of the current DAS *should be removed*?”

DAS	+	n.a.	
	-	Audio warnings	13% (1/8)
TRAN	+	n.a.	
	-	Audio warnings do nothing for me	13% (1/8)
	-	HUD	13% (1/8)
	-	Cut down on info in HUD - it's an overload.	13% (1/8)

“What things *would you like added* to improve the DAS?”

DAS	+	n.a.	
	-	Make the HUD more stable	13% (1/8)
	-	Change touch panel location to in front instead of off to the side	13% (1/8)
TRAN	+	n.a.	
	-	Streamline the current system, make it smaller and less bulky.	13% (1/8)
	-	Better combiner - more stable, constantly adjusting something while plowing.	13% (1/8)
	-	Not as it is now, only if it was made rock solid (components and functioning)- No intermittent satellite. When you're inches from killing innocent pedestrians, it has to be infallible.	13% (1/8)
	-	Doesn't pick up curves that well	13% (1/8)
	-	Too distracting as it is now.	13% (1/8)

Final Interviews

For the open-ended questions, subjective comments were separated by whether they were positive or negative in nature. Positive summaries and comments are preceded by a plus sign ("+"), and negative ones are preceded by a minus sign ("-"). Repeated comments were tallied and each comment is followed by the percentage of total drivers who gave this response.

DAS System (DAS)

System Acceptance

"What would be most annoying if they had to use the system for an extended period of time?"

-	HUD would be hard on your eyes eventually, probably get headache	22% (2/9)
-	The combiner because having to keep readjusting it all the time would be a problem	22% (2/9)
-	The audio warnings	22% (2/9)
-	The red square radar indicators picks up everything from the sides of the road	11% (1/9)
-	Anything after 12 hours is annoying, especially in blizzard conditions.	11% (1/9)

"What changes could be made to the HUD component to make it better?"

-	Make it more solid, it vibrates too much and should lock into place better.	56% (5/9)
-	Make it smaller or place it lower in my field of view (lower windshield or on dash)	33% (3/9)
-	Make it easier to adjust	22% (2/9)
-	Looking through combiner takes away depth perception and reduces what I can see	22% (2/9)
-	On (tight) corners, show more preview of the curve ahead	11% (2/9)

"What changes could be made to the haptic seat component to make it better?"

+	I didn't like sensory overload; the HUD is too much to worry about so I prefer the seat	13% (1/8)
+	(Of all the components,) I relied on the seat most often.	13% (1/8)
+	As long as I can adjust lane-center position, it's fine	13% (1/8)

"What changes could be made to the audio warning component to make it better?"

-	Get rid of it, I don't like when it cuts out my radio	28% (2/7)
-	It could make a more pleasant sound	14% (1/7)

System Performance

"Did the DAS ever cause you to make a mistake while driving?"
One third of the drivers (33% (3/9)) said that the DAS prompted them to make a wrong action or an error in judgment.

As a follow up: "If so, explain the mistake."

-	Coming up on obstacles, I couldn't tell how close I was: problem with depth cues or understanding cues.	67% (2/3)
-	Equipment boxes and false objects came up on radar (false targets)	33% (1/3)
-	When it stopped working (lost GPS fix & solution).	33% (1/3)

DAS System with Transitions (TRAN)

System Acceptance

"What would be your preference for a display during a loss of GPS fix?"

Components:	% Would Prefer
Haptic Seat Warnings	67% (4/6)
HUD	50% (3/6)
Audio Warnings	17% (1/6)
Other	0% (0/6)
Both the seat & audio	*17% (1/6)*
Both the HUD & seat	*17% (1/6)*

As a follow up: "Explain your recommendation."

+	I like the vibrating (haptic) seat the best. It is the most noticeable warning	50% (3/6)
+	Seat and audio, because they are easy during transitions	17% (1/6)
+	The HUD is easy to understand	17% (1/6)

"What is your preference for alternative ways to display lane information during a loss of GPS fix?"
Four drivers (67% (4/6)) reported that they would like to see some implementation of the tape backup system installed by itself in their truck.

As a follow up: "Why would you or would you not like this system implemented?"

+	It does the bare minimum: it's simple, cheap, and does essentially the same as the full DAS	50% (3/6)
+	It would be useful when the GPS goes out	50% (3/6)
+	Maybe, if it used the seat or audio	17% (1/6)
-	It was too sensitive	17% (1/6)
-	It would be useful if the display was refined	17% (1/6)
-	Tape output wasn't aligned with the GPS output, after transitioning the tape said you were 3ft over from where the GPS told you	17% (1/6)
-	I wouldn't use it much and feel it is not necessary	17% (1/6)

APPENDIX K – FINAL SURVEY / COMPARISON TO 2002 FOT

The final survey 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.

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 did not get 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 years 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 K-1.

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 K-1. 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 K-2.

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 K-2. 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 K-3.

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 K-3. 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 K-4.

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 K-4. 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 K-5.

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 K-5. 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 become more familiar and therefore 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 the 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 K-6.

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 K-6. 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 set up" and "streamline it, make it less bulky"). The other suggestion 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 ‘white outs’, 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.”

Appendix L – Comparison to a Previous Study

We compared subjective results from this study (questions from the Final Interview, page 86) to results from a study that examined a similar 3M magnetic tape lateral guidance system. Responses to questions were compared in order to see if there were any notable differences in opinion between the DAS (and the DAS while transitioning to the 3M backup system, i.e. TRAN condition) and this previous Lane Awareness System, or "LAS", using 3M magnetic tape guidance (McGehee & Raby, 2002).

The McGehee and Raby 2002 Study

The experimenters were under contract to develop and test a system to support 3M's Magnetic Tape Series 2000. To do this, they conducted a study in three phases. In the first phase, they conducted interviews and surveys to understand the demands and constraints imposed on plow drivers.

The second phase of their project was to design the interface based upon an operator function model and cognitive task analysis. They then proposed an interface consisting of a haptic seat and peripheral LED lights to convey primary lane departure warnings, and a control unit to provide detailed information on exact lane position. The intensity of the haptic seat warnings and brightness of the LED could be adjusted using knobs on the control unit. The control unit also allowed drivers to dim the electroluminescent display, toggle between tape sensors, and adjust the lateral warning thresholds for the right and left sides.

The final phase of their testing consisted of both a field operational evaluation in Arizona and Minnesota, as well as a closed-course usability study on Mn/ROAD. This closed-course study is what we based or comparison of the DAS on. In their study, they had participants drive Mn/ROAD with the LAS under dynamically varying levels of headlight illumination. They found that drivers liked the haptic seat warnings as well as using the peripheral lights as a compliment to the seat. Also, drivers liked being able to adjust the lane boundary thresholds on the control-display unit.

Both the LAS and the DAS utilize haptic seat for lateral warnings. The LAS provides lane position information on a display near the driver's radio controls. The DAS normally provides lane position information through the HUD and lateral offset warnings through the haptic seat and audio warnings. While utilizing the 3M magnetic tape system, the DAS only provides lane position information on the HUD.

The LAS provides warnings in the driver's peripheral vision in addition to the haptic seat and lets drivers adjust the intensity of both the seat and light warnings. The DAS provides audio warnings in addition to the haptic seat, but the ability to adjust and disable components was not allowed during the track testing.

Comparison Results

In the tables below, the results from our DAS condition are in columns labeled "DAS" and results from our TRAN condition are in columns labeled "TRAN." These results are out of eight drivers' responses. Results from the McGehee and Raby study are in columns labeled "LAS." These results are out of four drivers' responses.

DAS, TRAN, and LAS scores were compared using T-tests to analyze significant differences. All cases of statistical significance are reported in the text with the alpha level of significant (p). If a comparison was significant, this implies that the cases being compared were different in a meaningful way. Thus, if the DAS and LAS ratings were shown to have significantly different results on one of the questions, we can infer that the two conditions were in fact different (i.e. one system was rated better than the other). When a DAS to LAS comparison or TRAN to LAS comparison are significant, an asterisk (*) is placed next to the DAS or TRAN mean.

Again, there are two main differences between these systems:

- The DAS uses audio while the LAS uses peripheral LEDs to indicate lateral warnings
- The DAS displays lane position information on a HUD while the LAS uses the dash-mounted control-display unit

Differences of driver opinion between the two systems for the results below are most likely due to these system differences. Therefore, if one system is rated significantly better on a measure, we can make the inference that it is because of these system differences. This allows us to make design recommendations from these results.

Subjective Mental Workload

Overall mental workload measure results from the two studies are compared in Table L-1.

Measure	DAS	TRAN	LAS
Mental Workload (NASA-RTLX)	40	43	38

Table L-1. Comparison of the DAS and TRAN conditions to LAS results on mental workload

These mental workload results are from the NASA-RTLX scale, which asks drivers to rate how much effort they feel on specific types of mental effort. These results consist of the overall average of these scores on a scale of zero (low mental effort) to 100 (much mental effort).

Neither the DAS' nor the TRAN's mental workload score was significantly different from the LAS score. This means that drivers in our study rated using the DAS and the DAS with transitions to the 3M system to be just as mentally demanding as drivers using the LAS.

Subjective Questions

Similar questions were asked to drivers in our study as were asked to drivers testing the LAS. In the Highway 7 track testing, these questions were asked as a part of the final interview. LAS drivers answered these questions as part of their final survey.

During the Highway 7 testing, drivers were asked to rate their (dis)agreement with statements on a scale from 1 (strongly disagree) to 5 (strongly agree). During the McGehee and Raby study, drivers were generally asked to respond on an agreement scale ranging from 1 (not at all) to 7 (completely), with a few exceptions. Both sets of average agreement ratings for each grouping (DAS, TRAN, and LAS) have been standardized by converting the scores into percentages; Taking the average rating and dividing by the highest possible rating for that question accomplished this.

In all of the tables, the highest agreement rating (i.e. the highest percentage) for each question has been placed in bold text for emphasis.

Safety

Table L-2 presents questions relating to the Safety of the DAS, transitioning DAS, and LAS systems.

Question	DAS	TRAN	LAS
Using the (system) made me a safer driver	56% *	59% *	**83%**
The (system) in the HUD was helpful to maintaining lane position		50%	**56%**

* Significant at .05 level

Table L-2. Agreement to statements relating to the Safety of the DAS, transitioning DAS, and LAS

It appears that drivers in the McGehee and Raby study felt significantly stronger that the LAS made them a safer driver than our drivers did in either the DAS condition ($t = 2.66$, $p = .02$) or TRAN conditions ($t = 2.31$, $p = .04$). This suggests that a system such as the LAS, with only peripheral lateral warnings, may make drivers feel safer than a system that has both peripheral and continuous lane information in the center of driver's field of view.

Table L-3 presents questions relating to the Safety of the DAS and LAS systems.

Question	DAS	LAS
The (system) helped me spend less time looking for obstacles in the roadway	**58%**	54%
The (system) allowed me to spend more time doing other tasks	50%	**54%**
The (system) caused me to make a mistake while driving	**33%**	25%
The (system) made me more aware of my lane position	**81%**	75%
The warnings provided by the (system) enabled me to respond quickly to a lane departure	64% '	**88%**
Compared to not driving with the (system), I felt having it enhanced my ability to maintain lane position while driving on straights	72%	**83%**
Compared to not driving with the (system), I felt having it enhanced my ability to maintain lane position while driving on curves	36% *	**79%**

' Marginally Significant
* Significant at .05 level

Table L-3. Agreement to statements relating to the Safety of the DAS and LAS

McGehee and Raby's drivers agreed more strongly that the LAS enhanced their ability to maintain lane position while driving curves ($t = 5.13$, $p < .01$). Though it was DAS drivers' opinion that they had low preview distances in the HUD during the curves, drivers also had the haptic seat and audio lateral warnings to guide them.

Since both DAS and LAS drivers had haptic seat lateral warnings, this finding suggests that drivers using a peripheral lighting lateral warning feel that they can maintain lane position better in curves than drivers receiving audio warnings. In agreement with this implication, it was also found that LAS drivers agreed slightly more strongly that their system helped them respond quickly to lane departures ($t = 2.65$, $p = .07$).

Acceptance

Table L-4 presents questions relating to the drivers Acceptance of the DAS, transitioning DAS, and LAS systems.

Question	DAS	TRAN	LAS
I trusted the (system) to help me maintain lane position, as compared to trusting my own abilities	59%	56%	**67%**
The (system) provided useful information in addition to my traditional visual cues	**69%**	**69%**	67%
It was easier for me to drive while using the (system)	53% *	53% **	**92%**

* Significant at .05 level

Table L-4. Agreement to statements relating to the drivers' Acceptance of the DAS, transitioning DAS, and LAS

McGehee and Raby drivers agreed more strongly that it was easier to drive while using the LAS than the DAS ($t = 3.24$, $p < .01$) or TRAN ($t = 3.84$, $p < .01$) drivers thought of driving with their respective system. Again, this suggests that drivers may have been overwhelmed with the DAS and TRAN implementations since they confront drivers with information in the center of their field of view (HUD) in addition to peripheral lateral warnings (haptic seat, audio warnings).

Table L-5 presents questions relating to the drivers Acceptance of the DAS and LAS systems.

Question	DAS	LAS
The (system) was intuitive to me	56% *	**83%**
I imagine using the (system) for 12 hours would be annoying	33%	**38%**
The seat vibration was useful in helping me maintain lane position	69%	**83%**
I considered the seat vibrations annoying	**34% ***	6%

* Significant at .05 level

Table L-5. Agreement to statements relating to the drivers' Acceptance of the DAS and LAS

McGehee and Raby drivers agreed more strongly that the LAS was more intuitive (t = 3.30, p < .01). Again it seems that the advantages of seeing the lanes on the HUD may have caused drivers to feel that this system was less intuitive than the LAS.

LAS drivers also disagreed more than DAS drivers (t = 2.79, p = .03) that the seat vibrations were annoying. These warnings were implemented similarly in both studies, the only difference being that LAS drivers could change the intensity of these warnings from a knob and for DAS drivers to do this they had to navigate through a menu and drag a "soft" scroll bar.

Having the ability to change this quickly in the LAS, possibly even without looking, may have caused drivers to like the haptic seat more. Though this is hard to tell from the Highway 7 track test results, since drivers were not allowed to change this setting.

Reliability

Table L-6 presents a question relating to the Reliability of the DAS and LAS systems

Question	DAS	LAS
The (system) was reliable	72% *	**89%**

* Significant at .05 level

Table L-6. Agreement to statement relating to the drivers' Acceptance of the DAS and LAS

LAS drivers felt more strongly that the LAS system was reliable than DAS drivers felt their system was. Knowing that the DAS had more lane assistive and lateral warning elements, this suggests that drivers felt that with seemingly more complex components, there was the possibility of more things going wrong. The TRAN condition itself may have also confounded this result; since by it's nature it simulated the DAS losing the GPS signal frequently.

Discussion and Design Recommendations

From these results, it is hard to make general conclusions, since the number of drivers in each study was small and the systems they were using, though comparable, were implemented differently. The major difference between the systems was how the main interface provided information: the LAS' control unit was a display in the driver's periphery, and it also provided peripheral light lateral position warnings; the DAS' HUD was in the driver's main field of view, and it also provided audio lateral position warnings.

Overall the DAS and LAS were found to be useful to the drivers in each study, both to maintain lane position as well as to provide useful information quickly. However, drivers did seem to think that the DAS was not as easy to use while driving, was less reliable, and was not as useful during curves.

In this case, the detailed nature of the HUD display may have been it's bane in that drivers expected to see an exact match between the display and the real world. If so, any inconsistencies, whether meaningful or inconsequential, would be seen as weaknesses and usefulness of this type of display. When using this type of display, it needs to be made clear that the HUD is meant to be a general guide to where the lanes are and not a detailed representation of the road.

This suggests that drivers prefer and feel more comfortable utilizing peripheral lateral warnings (e.g. LED lights) to information in the center of their field of view (HUD lane assistance). It also suggests that LED light peripheral warnings are more accepted and advantageous over audio lateral warnings.

It is recommended in future lateral position warning systems consider using more natural cues that utilize drivers preference for peripheral cues as opposed to central field of view. Here should be emphasized the haptic seat warning and the LED light warnings. The exception to this is audio warnings, since they are peripheral warnings that drivers tended to dislike.