

UC Berkeley

Working Papers

Title

Preliminary Findings for a Lane-Keeping and Collision-Warning Driver Interface for Snowplow Operations

Permalink

<https://escholarship.org/uc/item/4b23b52c>

Authors

Steinfeld, Aaron
Tan, Han-Shue

Publication Date

1999-05-01

CALIFORNIA PATH PROGRAM
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

Preliminary Findings for a Lane- Keeping and Collision-Warning Driver Interface for Snowplow Operations

**Aaron Steinfeld
Han-Shue Tan**

**California PATH Working Paper
UCB-ITS-PWP-99-6**

This work was performed as part of the California PATH Program of the University of California, in cooperation with the State of California Business, Transportation, and Housing Agency, Department of Transportation; and the United States Department Transportation, Federal Highway Administration.

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California. This report does not constitute a standard, specification, or regulation.

Report of the Advanced Snowplow Project

May 1999

ISSN 1055-1417

Preliminary Findings for a Lane-Keeping and Collision-Warning Driver Interface for Snowplow Operations

Aaron Steinfeld and Han-Shue Tan
California PATH
U.C. Berkeley

Abstract

This paper describes the development process and some preliminary findings for the human-machine interface (HMI) component of a system to aid snowplow operators. The HMI was developed through a series of driver task explorations and prototype tests. The HMI design has resulted in positive driver feedback and quick learning periods.

Word count: 50

Keywords

Driver assist system

Snowplow

Lane keeping interface

Collision warning interface

Human factors – snowplow

Executive Summary

This paper describes the development process and some preliminary findings for the human-machine interface (HMI) component of a system to aid snowplow operators during adverse, low-visibility conditions. The system provides information on lane edges, lateral position, and potential forward collisions. The HMI component was developed through a series of driver task explorations and prototype tests.

Short practice effect curves were seen on a prototype lateral assist system with drivers achieving a steady state at the third trial. The subsequent operational system resulted in positive driver feedback and quick learning periods when deployed in the Lake Tahoe region. Drivers in this region were observed to emulate the short learning curves seen with the prototype.

Surveys and limited driver behavior data were collected at the Flagstaff, Arizona site. The surveys indicated that drivers had positive impressions regarding ease of use and appeal. The surveys also reinforced the short learning curves in that drivers generally felt they would be comfortable with the system with under a month of use. Behavior data showed that the short learning curves seen with the prototype could also be associated with the operational system.

In general, driver comments were positive and optimistic that the system would benefit their safety and efficiency. The drivers' fast acquisition of the system bodes well for future iterations and eventual deployment. Their suggestions for HMI improvements have been very helpful and will be combined with the objective findings to improve upon the system. Subsequent iterations will include continuous improvements to the HMI.

Introduction

Overview of the problem

The Advanced Snowplow (ASP) project was initiated to assist snowplow drivers during the harsh conditions often experienced over Donner Pass on Interstate 80 in the Lake Tahoe region. (For more information on the system concept see Stone, 1998 and Zhang, et al, 1999.) Snowplow drivers along this route experience some of the heaviest snowfall in the United States and often encounter white-outs due to the sheer quantity of snow as well as blowing winds in the mountainous terrain. During the frequent winter storms, drivers operate snow removal equipment 24 hours a day since Interstate 80 is the major land conduit into northern California.

Besides pushing snow, a snowplow driver has to give simultaneous attention to a set of secondary tasks. First and foremost, they need to stay on the road; a somewhat difficult task during white-out conditions. Experienced drivers learn to feel the road surface through the plow blade. The change in texture or pitch of the shoulder can provide subtle vibration cues through the truck body and the steering wheel. Traditional wisdom would recommend that the driver come to a stop and wait out the period of low visibility. However, in mountainous terrain drivers are often reluctant to do this since stopping on an incline or in a potential avalanche area is undesirable.

A subtask of staying on the road is maintaining a position within a lane. Even during periods of good visibility and without deep snow, this can be difficult since road markings are not easily perceived (Figure 1). In some regions (such as Donner Pass) a team of plows is used in formation. The position of the lead plow is especially important. The drivers following behind will adjust their lateral position based on the lead plow.



Figure 1. A typical view from the cab of a snowplow at Donner Pass (a forward plow is seen at the left shoulder, the lead plow is barely visible)

Another fundamental task is to avoid driving the plow into an obstacle (e.g., a car stuck in a drift). In low visibility conditions, an experienced plow driver will feel the plow blade make

contact with such an obstacle. Since the driver has typically dropped to a very slow speed, the initial contact is usually not extreme. Furthermore, the driver can stop the plow quickly by dropping the plow blade into the ground. This stopping technique is even more effective when the plow is equipped with a wingplow (a large plow mounted on the side of the truck). Even with this rapid stop, it is possible to damage the obstacle and/or the snowplow.

The driver's basic duties are further affected by a series of potential hazards. Low visibility can occur due to white-outs, malfunctioning or iced headlamps, or a soiled windshield. Perception of the road edges is affected during deep snow conditions since the only indications of the edges are tall snow stakes placed just off the shoulder. Additionally, vehicle dynamics can be adversely affected by icy roads, plow vibration, and icepacks. When a wingplow is in use, low ballast (due to sand depletion) can also lead to extreme torque on the truck. These difficulties can easily lead to elevated levels of mental workload and stress.

Human factors goals for the Advanced Snowplow project

The primary human factors goals of this project were to provide to the drivers with information on lane edges, lateral position, and potential forward collisions so that they could navigate more safely, efficiently, and confidently through low visibility conditions. A secondary goal was to provide lateral information in a manner that would make positioning the lead plow during deep snow scenarios easier.

Prototype Development

Human-machine interface design considerations

The characteristics of the human-machine interface (HMI) of interest were the look-ahead distance, the road representation, and the presence of a prediction marker. The look-ahead distance is the longitudinal location that the display is describing. The road can be described with a bar (a single lateral slice at a set distance) or some iconic representation of the road scene. Prediction of future position and/or orientation can be supplied using internal maps, vehicle orientation, speed, and current lateral position. The first mini-study examined the impact of look-ahead distance while the latter characteristics were examined in the second mini-study.

First mini-study: Bar displays

A simple visual display that would only require a quick glance was a key design goal. Auditory displays were not considered since the cab interior is often noisy during operation.

A preliminary mini-study using a Buick LeSabre was conducted to support the HMI development. Simple modifications of an Automated Highway System equipped Buick were made by disabling the steering actuator action and processing the lateral deviation information to reflect different look-ahead distances. The lateral deviation from the centerline was presented on a small bar in a Delco Head-Up Display.

To test the bar display, 3 members of the development team who had not been exposed to the display were enlisted as drivers. Drivers were tested with a covered windshield (simulated white-out) using 0, 5, 10, and 15 meter look-ahead distances. The speed was fixed and automated at 13 mph (6 m/s). All driving was done on a short, closed-track course. All mini-

studies were conducted on the PATH Richmond Field Station track (Figure 2), which is about 320 m long and includes several short curves. Data was sampled at 33 Hz.

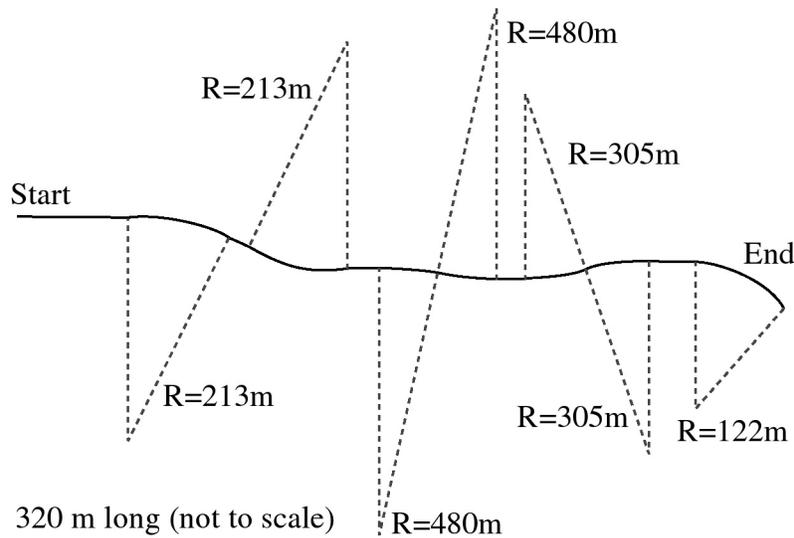


Figure 2. PATH Richmond Field Station track

Figure 3 shows two runs with look-ahead distances of 0 and 15 meters, respectively. (Distances of 5 and 10 meters showed a smooth progression between the two shown.) The results indicate that the larger look-ahead distances lead to better lane-keeping performance. Off scale events indicate the centerline magnets are beyond the range of the car's magnet sensors (i.e., the car is out of the lane). Lateral deviation is the lateral displacement from the center of the lane as measured by the sensors under the front bumper of the car. (This measure will be referred to as front lateral displacement in later sections.)

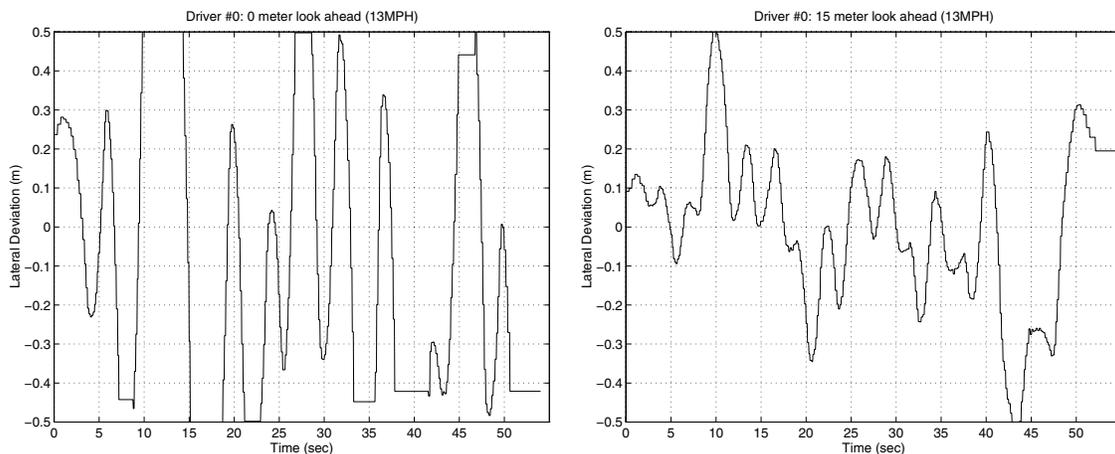


Figure 3. Lateral performance of Subject 0 (0 and 15 meter look ahead distances)

Drivers commented that this display method required high concentration levels. It was felt that the addition of one or two additional bar code indications (reflecting the road and vehicle trajectory change) would help drivers improve performance.

Second mini-study: Road images

The need for a respectable look-ahead distance and the concern over the unacceptable amount of driver stress led to the desire to examine displays with multiple bars. The inclusion of more rows allowed miniature, iconic road scenes to be examined. This design was reinforced by initial contacts with the snowplow drivers who suggested a visual display that indicated lane position and road edges. Figure 4 presents an example of one of the text-based prototype displays that were created.

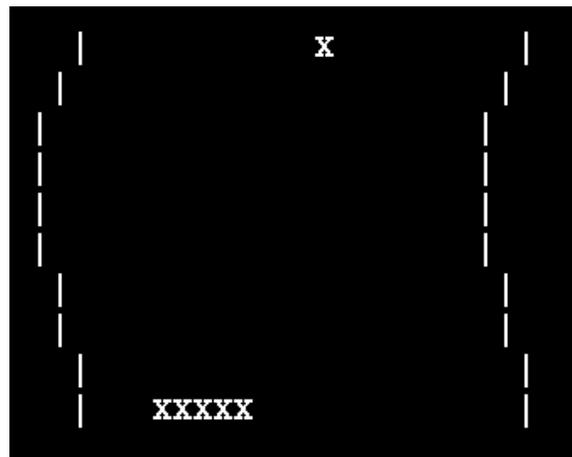


Figure 4. A text based representation of the road

A prediction feature was also added into the top line of the display. The single “X” showed the lateral position corresponding to the magnitude and direction of the steering wheel angle (turn left, the X moves left). The display represented a distance of 10 meters with a one-meter width between the “curbs.”

To assist final selection of relative motion, two versions were created. One showed the scene with the car (“XXXXX”) fixed at the same location on the screen (fixed car). The other fixed the curbs on the bottom row at the same location while the car moved side to side (fixed road). Since the display never went beyond the computer window edge, some drivers may have perceived the two displays as being equivalent.

Since the snowplow was being outfitted, the character display was installed on a Buick LeSabre to allow ongoing development (Figure 5). The simulation of low visibility was achieved by masking a portion of the windshield with paper. The resulting simulated snowplow was also used to elicit further design suggestions from members of the development team. As in the first mini-study, the windshield was covered to mimic the worst-case whiteout condition. The peripheral view was visible and a team member sat in the passenger seat as a safety precaution.



Figure 5. An experimenter driving from the character display with a simulated white-out

Four members of the development team who had not been exposed to the display acted as subjects for this mini-study. Exposure to the fixed car and fixed road displays was counterbalanced. A trial with a smaller version of the character display was run first for practice. Table 1 shows the sequence for each subject.

Table 1. Display sequence for each subject

Subject	Trial Sequence		
	1	2	3
1	Practice	Fixed Road	Fixed Car
2	Practice	Fixed Car	Fixed Road
3	Practice	Fixed Car	Fixed Road
4	Practice	Fixed Road	Fixed Car

Figure 6 shows that the iconic road display with prediction was quite effective for maintaining lateral position. Note that this driver stayed within a range of a half-meter at the extremes and about 0.3 m for the bulk of the course. Front lateral displacement (FLD) corresponds to the lateral displacement from the center of the lane as measured by the sensors under the front bumper of the car. The car was also equipped with sensors under the rear bumper, but only the values from the front were used for analysis.

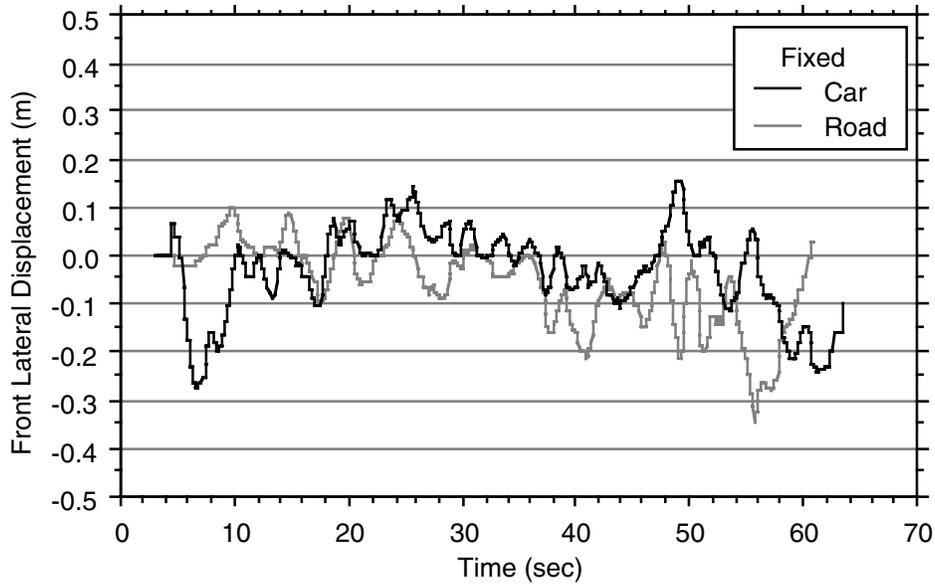


Figure 6. Lateral performance of Subject 2

While the speed was fixed for the first mini-study, the drivers were given control in this study (Figure 7). The drivers were instructed to maintain a speed between “10 to 15 mph.” Drivers generally reached a speed plateau near the previous study’s 13 mph (6 m/s, 1 mph = 0.44 m/s). Drivers began and ended at a stop (speeds less than 1 m/s were not recorded).

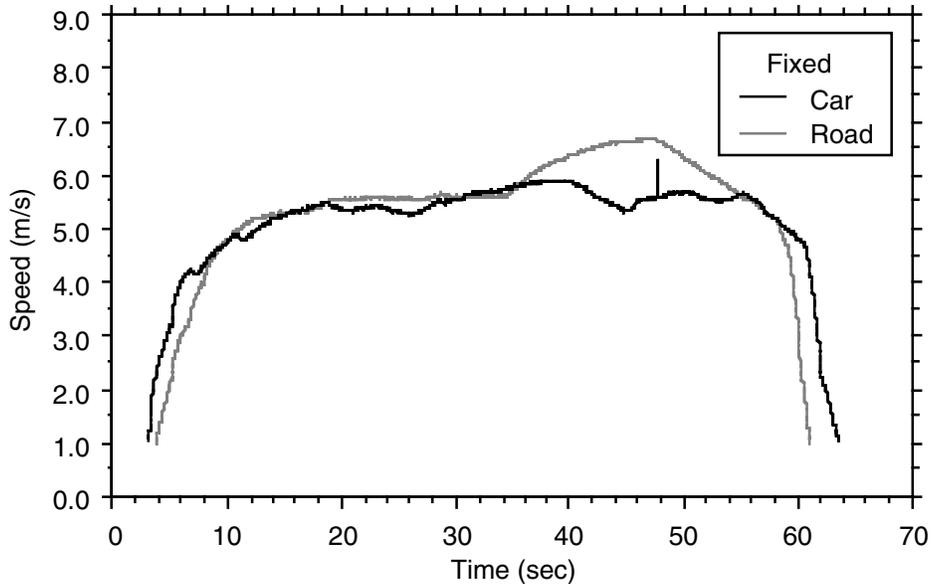


Figure 7. Speed performance of Subject 2

The fixed-road display led to slightly faster speed performance, suggesting the display was easier to use (Figure 8). The considerably slower speeds seen for the straight and 122 m radius segments are due to the drivers speeding up and slowing down at the start and end of the track

(as seen in Figure 7). The lateral performance was somewhat inconclusive (Figure 9). In general, the tighter curves seemed to produce slower speeds and more lateral deviation.

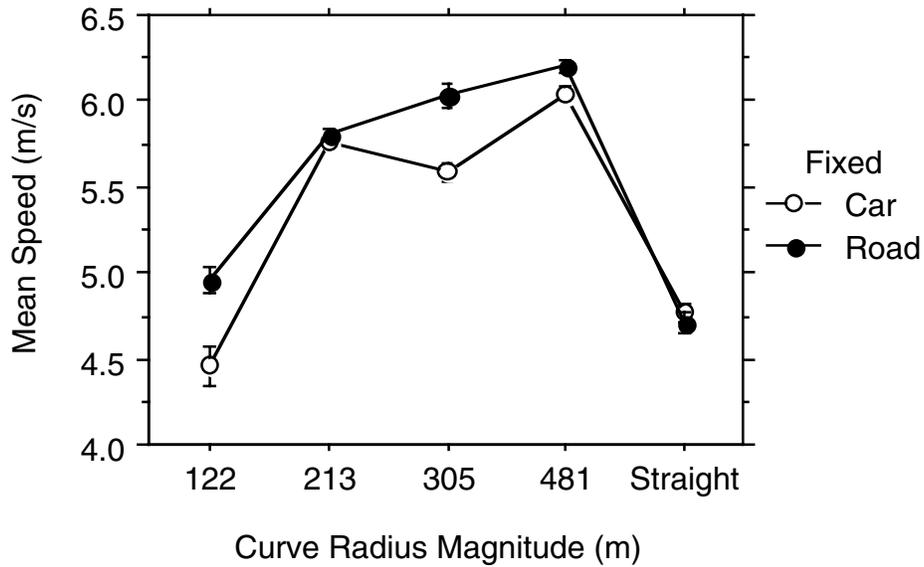


Figure 8. Mean driver speed as a function of curve radius and display type (with 95% confidence intervals)

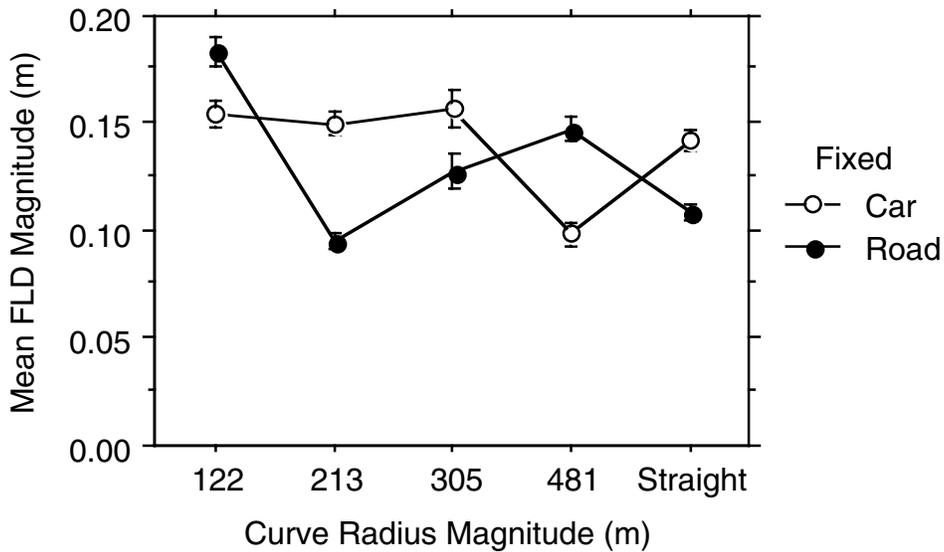


Figure 9. Mean forward lateral displacement magnitude as a function of curve radius and display type (with 95% confidence intervals)

The standard deviation behavior data (Figure 10) is inconclusive on which part of the display to fix (car or road). Larger steering wheel and speed standard deviations imply that the driving task is more difficult (proximity to the origin of Figure 10 suggests an easier task).

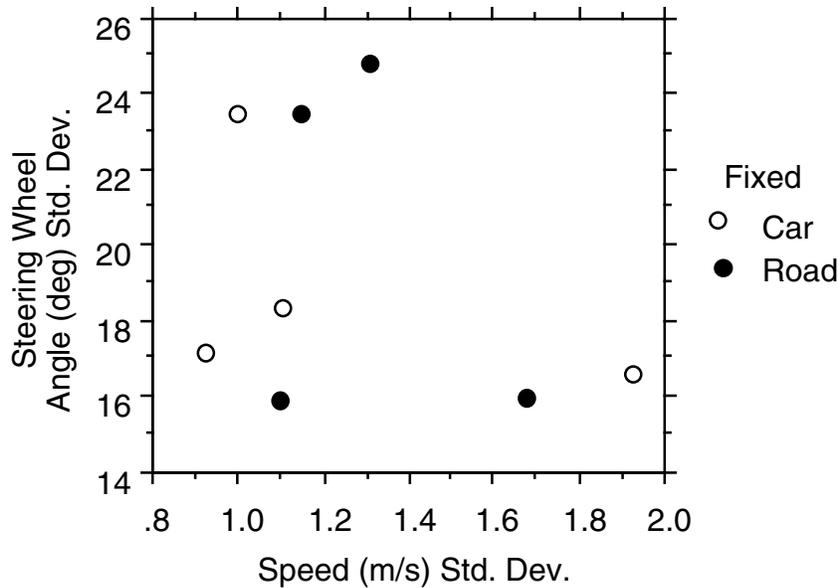


Figure 10. Standard deviation data for second mini-study

One potential useful finding is that actual lane positioning was worse for the fixed car display (Figure 11). All curves on the track, with the exception of the 122 m radius curve, had counterparts that curved in the opposite direction. The curve pairs are within a few meters of each other in arc length. The better lateral position, coupled with the slightly better speed performance over curves results (Figure 8), lend credibility to tentatively endorsing a fixed-road display. A firmer endorsement cannot be made due to the predominance of inconclusive findings and the small subject pool.

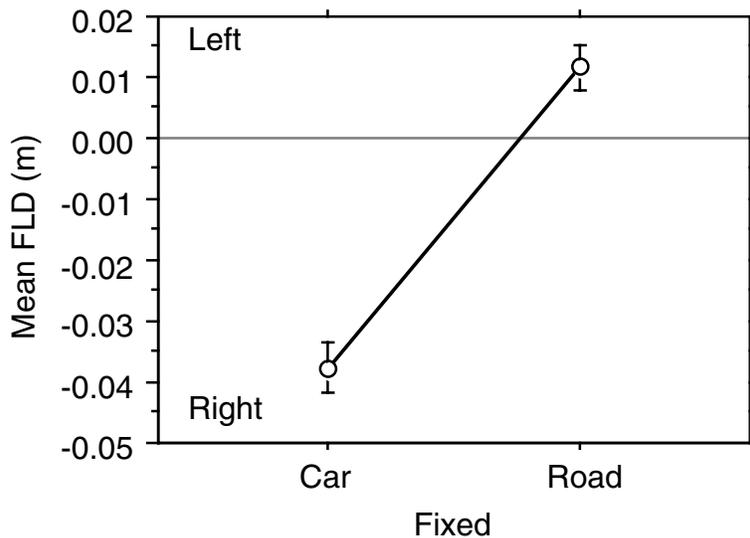


Figure 11. Mean lateral displacement from lane centerline (122 meter radius removed, with 95% confidence intervals)

Regardless of the display, a rather promising practice trend was seen for both speed and lane deviation (Figure 12). The previously mentioned practice trial was run with a display that was

half the size of the others. It was not included in the analysis above. The increase in speed and reduction in lane deviation (especially between trials 1 and 2) suggest that there was a promising learning curve present. This has positive implications for the final display.

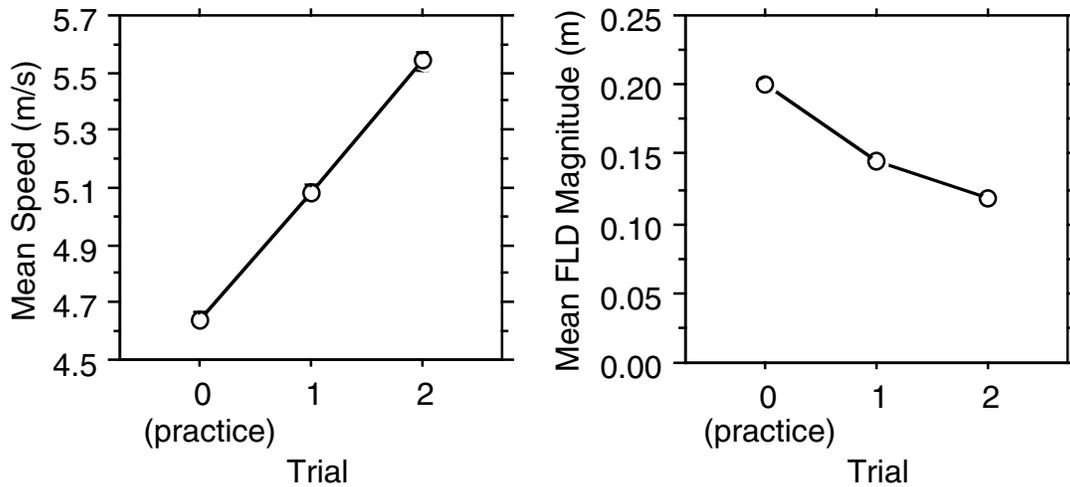


Figure 12. The impact of practice (with 95% confidence intervals)

The practice effect was also visible in informal observations. During demonstrations of the system to other team members, drivers were asked to drive at 10-15 mph using the fixed-road character display. Drivers typically adapted to the system after two runs. Their FLD magnitude also tended to drop down to levels similar to Trial 2 in Figure 12.

Third mini-study: Practice

The practice trends observed in the second mini-study led to a pair of small tests. The first examined the effect of practice with long breaks between trials, while the second had much shorter break durations. Since the experimenter (AS) was also the subject for both tests, the windshield cover used in the second mini-study was replaced with a small piece of cardboard. This made observing the magnets difficult but allowed the experimenter to see the road and notice potential hazards. (The magnets do not stay in the center of the paved road and there are no lane markings.) Such a modification permitted solo drives and simulated conditions where lane markings were not visible. The fixed-road display from the second mini-study was used.

The long-break version consisted of 7 single trials spaced 5 hours to a day apart. Speed began to reach a steady level after the 3rd trial (Figure 13). The means were computed using the interior portions of the test track (no start-up acceleration or end-trial deceleration). Mean speed was computed across the test track subsections.

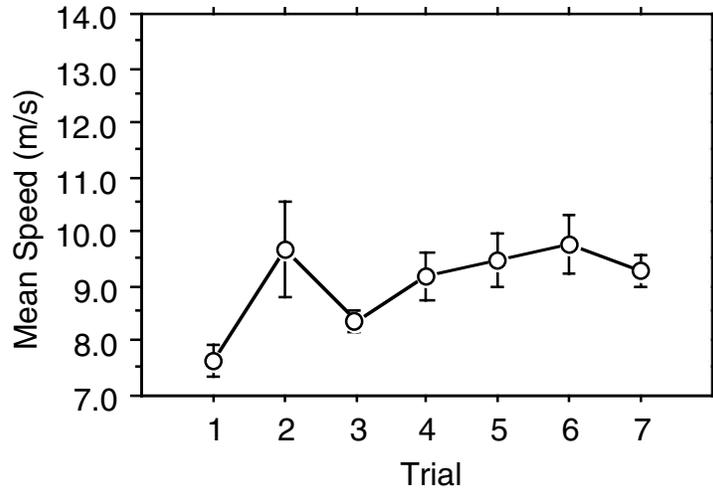


Figure 13. Speed behavior for long-break practice (with 95% confidence intervals)

The short-break duration consisted of 12 trials run in sequence, beginning with the last long-break trial. The break between trials was the amount of time necessary to save the data and bring the car back to the start of the track. Speed, steering wheel angle standard deviation, and lateral deviation magnitude began to level at the 3rd trial (e.g., Figure 14, also interior means). Thus, in both versions, the initial learning period was consumed with approximately 3 trials. Of side interest was that the short-break curve began at the level of the long-break trials.

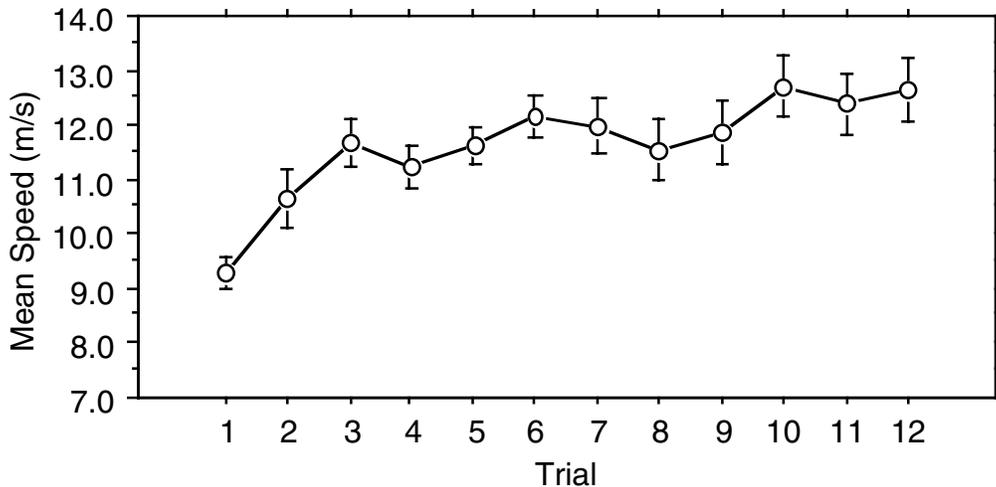


Figure 14. Speed behavior for short-break practice (with 95% confidence intervals)

While this data should be treated as preliminary due to the single subject and his familiarity with the display, the results are still quite promising. They reinforce the findings from the second mini-study in showing that drivers adapt quickly to the display.

Operational System

Following character display demonstrations for members of the California Department of Transportation (Caltrans), a more sophisticated and informative display was developed for the plow. This display included collision-warning information derived from a forward-looking millimeter wave (MMW) radar which could track three targets at a time. However, the initial version of the system was not able to detect the lateral angle of the targets.

Figure 15 shows an illustration of the display. The left-hand section contained the collision warning information. Downward-moving tapes showed the distance to each of the forward targets. Tapes were chosen because the drivers expressed a desire to know the distance to a potential obstacle. As a result, abstract and single event warning methods were not used (e.g., Dingus, et. al, 1997 and Yoo, et. al, 1996). Targets were only shown when they were within 100 m of the plow. The tape changed from yellow, to orange, and then red as the target approached (color changes at 50 and 25 m). The number at the bottom of the display was the distance to the closest target in meters (Caltrans is a metric operation). Upon initial installation, the radar sensor could not identify the lateral position of the targets. Future iterations will place targets in their matching lateral position (left, middle, right).

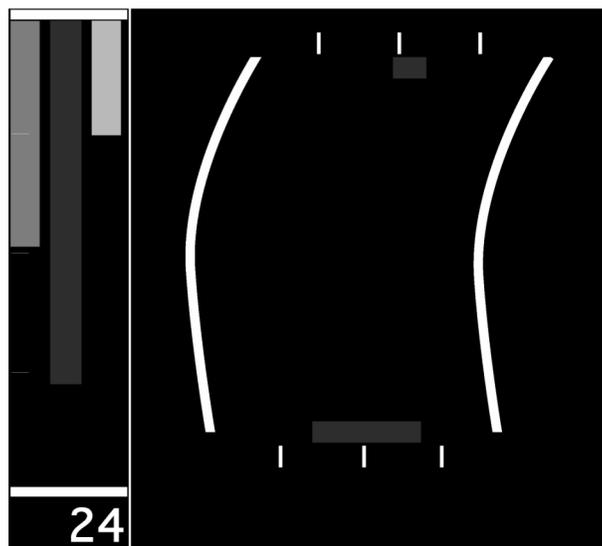


Figure 15. A drawing of a display scenario

The lateral display is similar to the character display, but included lane position marks and color coded system status information. In addition, the prediction capability was extended to 20 m and the displayed logical lane width was 2 m. The center tick marks indicated the center of the lane, while the exterior tick marks indicated 2 foot offsets (used during certain plowing formations). Under normal conditions the lines were white and the current and prediction markers were red. If the computer was uncertain of its current longitudinal position on the track, but was detecting position markers, the whole lateral display turned yellow and showed a straight road. This signaled to the driver that the display should not be trusted completely. If the plow left the magnets, the color changed to gray and froze. After a short time off the magnets, the lateral display blanked out.

The display was presented to the driver on a LCD panel in the center console area (Figure 16). This panel was in line with the wingplow mirror on the right nose of the hood. The plow blade controls were to the right of the driver immediately behind the floor-mounted gearshift.



Figure 16. Location of the display in the cab

The display location was chosen due to severely limited space and the presence of essential dials and controls on the dashboard. The choice of using a LCD panel was due to time and cost constraints. Two Head-Up Displays (HUD's) were briefly considered but rejected for display specific reasons. The first HUD was a set of special goggles that were rejected due to previous Caltrans exposure to head-mounted equipment. Past experience strongly discouraged such arrangements. The off-head HUD examined was rejected due to cab size constraints. The only usable location was above the steering wheel and near the visor at the top of the windshield. This was viewed as not satisfactory due to the possibility that the driver's head might collide with the unit during a crash or quick deceleration. Projections from behind the driver onto the windshield were not considered due to cost and the lack of space behind the driver's seat. (When the seat was all the way back, it touched the rear wall of the cab.) In addition, there were safety concerns with having a projection unit mounted near the driver's head (e.g., body motions during side impact crashes).

The team is now searching for a smaller panel display so that other locations can be considered. Field observations of the display also indicated that the "black" on a LCD was not black enough during night conditions. Thus, the team is also investigating panel displays with true black backgrounds. Future iterations will likely include explorations of other display techniques (e.g., HUD's, auditory assistance, etc.). More information on the ASP can be found in Appendix A.

Winter 1998/99

During the winter of 1998/99, the ASP was used in two locations. The plow was based at Donner Summit in California for the bulk of the winter. However, there was also a two-week demonstration at US 180 north of Flagstaff, Arizona during March.

California operation

The system was introduced during December 1998 along a portion of Interstate 80 at Donner Summit in the Lake Tahoe area. The test track is at a high elevation (average of 5,500 feet) and records large snow accumulations (as much as 54 feet of snowfall a season with roadside accumulations reaching 20 feet high). White-outs are common due to blowing wind and the sheer volume of snow. The stretch of road instrumented with magnets is a divided, restricted-access highway with 3 lanes and wide shoulders travelling uphill and west between the Donner Lake and Castle Peak interchanges. The test route starts about halfway up the northern slope of the Donner Lake valley and ends at the pass summit on the west end of the valley.

Caltrans driver training consisted of a description of display characteristics, a short run over a line of magnets in the maintenance yard, and a longer run on the instrumented test route. The learning period was observed to be very short (as seen with the prototype).

While computer-based driving data has not yet been systematically collected for the Donner Summit installation due to other project activities taking precedence, the experimenters have had numerous discussions and ride-alongs with the drivers. To date, the drivers have expressed that they like the system and that it enhances their confidence during adverse conditions. They have been generally positive about the implementation.

Observations during ride-alongs indicated that the drivers were able to use the display either for reference or as a primary driving mechanism. It was also apparent that snowplow driving has the potential to be a high mental workload, high stress job. This observation is especially obvious when the driver utilizes the wingplow and sand spreader controls in addition to the standard, forward plow. Other demands arise from gear shifting (the ASP has 13 gears), difficulty with the lights icing, and having to monitor surrounding traffic. As the Lake Tahoe region is a tourist destination for many people not accustomed to driving on snowpack and ice, snowplow drivers often encounter drivers who have skidded off the road or drive in an unsafe manner.

Arizona demonstration

The instrumented stretch of US 180 in Arizona consists of a two-lane undivided rural mountain road with frequent white-outs due to high winds. As this road is not a major Interstate there are areas of tighter curves and steeper grades than seen at the California track. The ASP was in Arizona for two weeks at the end of the 1998/99 winter. As such, there were only a few runs that were completed under snowing conditions; otherwise the pavement and weather were clear.

Seventeen Arizona Department of Transportation (A DOT) snowplow drivers were introduced to the system in a more controlled manner than at Donner Summit due to the much shorter amount of time that the plow was present. Initial training consisted of three team leaders being instructed by people from Caltrans and PATH. The Caltrans trainers rode along with each team leader for one or two circuits along the test route in order to teach the basics of driving the ASP truck. The ASP is quite different from typical A DOT plows in that it has more power, is larger, and has more gears. Following this, a PATH member would replace the Caltrans member and train the driver on the use of the HMI. An initial circuit with only basic instruction was conducted first, followed by a more detailed description of HMI characteristics and additional circuits of practice. The team leaders repeated this training pattern for the rest of the A DOT snowplow operators present at the two week demonstration.

Surveys

At the end of each training session, the drivers were asked to complete a two-page survey on the ASP HMI (see Appendix B, the rating scale was inverted after the data was collected to make analysis and discussion simpler). The results (Survey A, Table 2) indicate that the drivers had a high regard for the system. The lane-keeping portion of the display scored slightly higher than the collision-warning system (CWS). This difference is probably due to a lack of trust of the CWS detection performance. The system did not detect objects perfectly; false positives, misses, and warnings that did not readily disappear were not uncommon. A second survey was also given to the drivers. This survey included the time spent on the ASP and ratings on a variety of questions. Two of the questions (Survey B, Table 2) targeted safety and efficiency. Drivers consistently responded in a positive manner for these questions. Only one driver rated the system below a 7 for the safety question. His comments indicated concern regarding speed and engine rpm maintenance.

Table 2. Survey Results

	Mean	Std. Dev.	Std. Error	Count	Min	Max
Experience (years)	5.77	3.17	0.77	17	1.5	11
Time on ASP (hours)	4.88	5.06	1.26	16	2.0	20
Survey A: Ratings (1 - 5, higher being better)						
Overall: Easy to use	4.53	0.80	0.19	17	2	5
Overall: Like	4.71	0.59	0.14	17	3	5
Like More with More Practice	4.63	0.89	0.22	16	2	5
CWS: Easy to use	4.31	0.87	0.22	16	2	5
CWS: Like	4.38	0.96	0.24	16	2	5
Lane Keeping: Easy to use	4.44	0.63	0.16	16	3	5
Lane Keeping: Like	4.69	0.60	0.15	16	3	5
Survey B: "Potential to improve Your..." (1 - 10, higher being better)						
Safety	9.18	1.59	0.39	17	4	10
Efficiency	9.12	0.93	0.23	17	8	10

A reasonable hypothesis is that snowplow driving experience and exposure to the ASP would lead to higher opinions of the system. Extensive snowplow experience, and thus more on-road exposure, would probably result in having seen or been involved in situations where the ASP would be recognized as useful. Increased exposure to the ASP likely led to greater familiarity, which in turn produced more positive ratings. (The three A DOT trainers recorded the most time in the plow.) Figure 17 illustrates that such patterns existed. These trends are promising in regard to possible deployment of ASP technologies.

Driver behavior data

When the plow was brought to Arizona, it was necessary to calibrate the internal map to the new test site. During system testing, data was collected on speed and lane position characteristics at 30 Hz for about 1680 m. Prior to the data collection period, the driver drove along a longer stretch (about 4820 m) under identical conditions. Therefore, the data was collected for the last segment of each run. The data presented here is only for one driver and thus, should be considered preliminary, at best.

The data collection permitted a comparison of normal and HMI-assisted driving. The driver was asked to try to drive with of the HMI during a series of aided runs. Please note that there were clear views, dry roads, and the plow blade was lifted. Normal driving in this case corresponds to ideal conditions. The normal run was collected after several aided runs had been completed. Note that as the driver becomes more familiar with the system, performance approaches normal, unassisted driving (Figure 19). ANOVA analyses of Run (Normal, 1, 2, 6) revealed significant differences for both speed ($F = 4140, p < .0001$) and FLD magnitude ($F = 39.8, p < .0001$) as dependent variables.

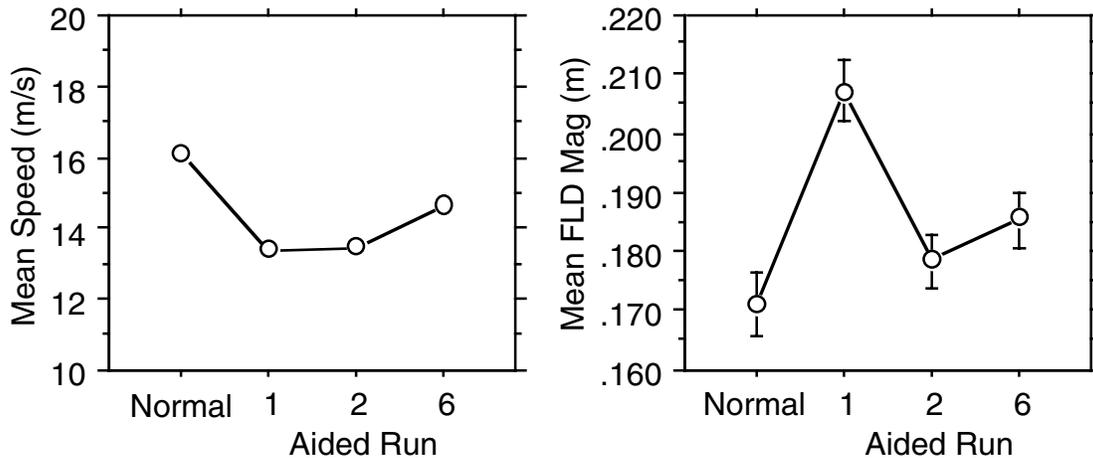


Figure 19. Driver behavior data during system testing in Arizona (with 95% confidence intervals)

There were five curves within the segment examined above. Figure 20 further illustrates the increase in driving speed as practice runs accumulated. It is apparent that, with increased experience, the driver approached his speed pattern under normal driving.

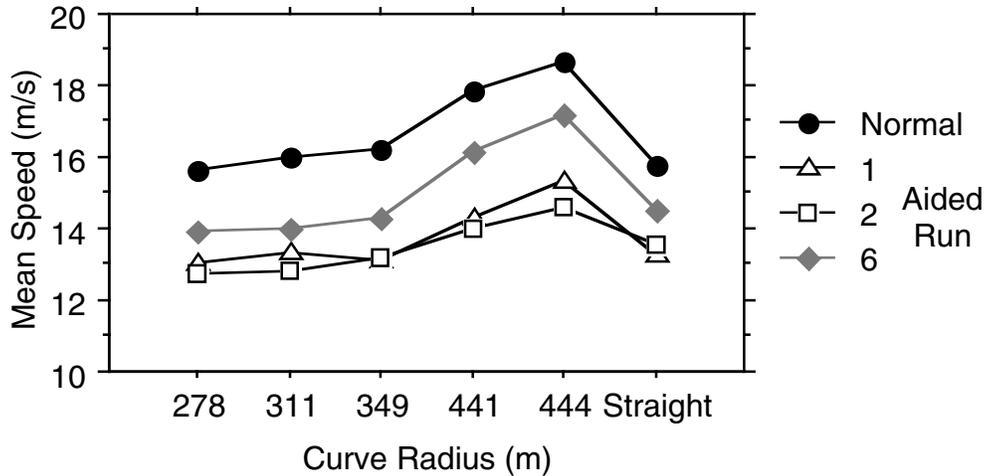


Figure 20. Mean speed as a function of curve radius

Further analysis across curve radius showed that increased experience led to more consistent lateral positioning. Figure 21 shows that the driver had a more stable position in the road. In fact, the tight curves (278 and 311 m) did not seem to affect the driver.

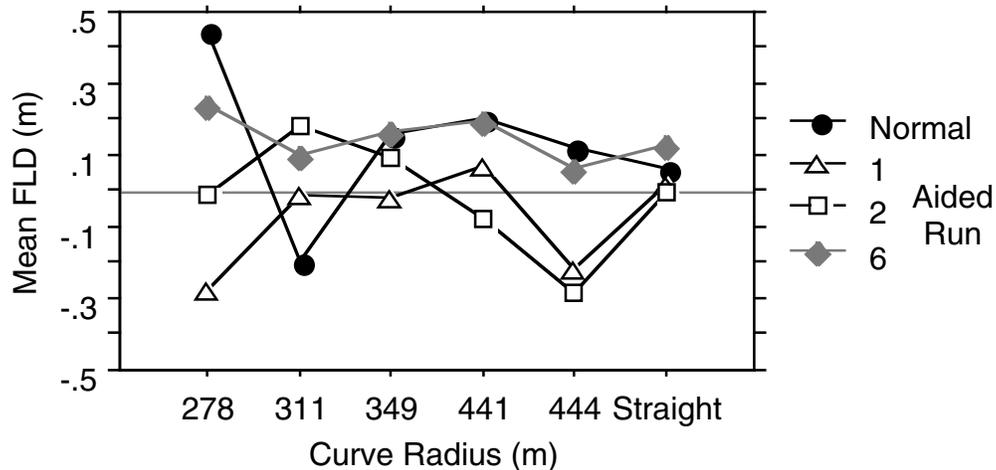


Figure 21. Mean FLD as a function of curve radius

As previously mentioned, larger steering wheel standard deviation implies that the driving task is more difficult. Figure 22 suggests that the task became easier as the driver's experience increased. Furthermore, the driver seemed to approach the driving difficulty levels of the normal run. This bodes well for low visibility scenarios and implies that it might be possible to reach mental workload levels similar to those of normal driving with good visibility and road surface conditions.

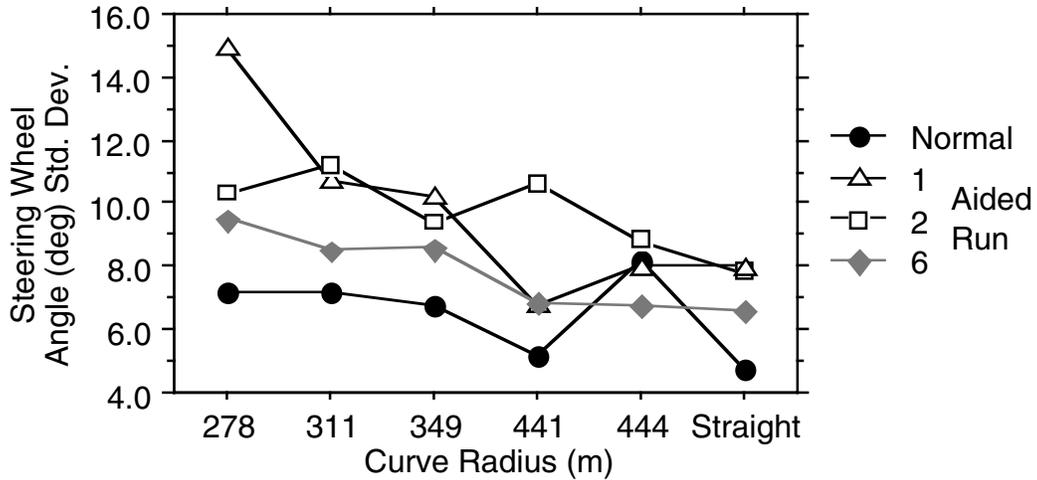


Figure 22. Steering angle standard deviation as a function of curve radius

The decrease in driving difficulty reinforced by the clustering of the normal and 6th aided run near the origin in Figure 23. Reduced levels of standard deviation for both steering wheel angle and speed are typically associated with easier driving. The four points to the right (Speed SD > 1.0 m/s) correspond to the data derived from the straight portions of the track. The higher speed standard deviations are probably due to accelerations and decelerations before and after curves.

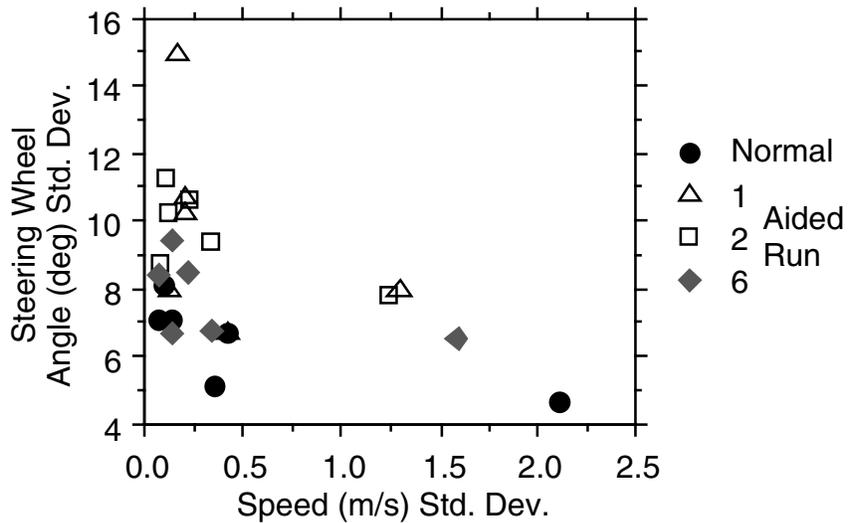


Figure 23. Standard deviation data

Conclusions

From the initial work conducted during this project, it is clear that the ASP system has the potential to be quite beneficial to driver safety and confidence. The ability to traverse low-visibility areas at faster rates of speed should also lead to improved efficiency during snow removal operations.

The findings from the lateral-assistance portion of the HMI suggest that, with proper instruction, the interface is intuitive and easy to learn. Most drivers were observed to reach a stable level of performance using both the prototype and the ASP after only 3 trials. Anecdotal comments and experimenter observations also suggest that the HMI can be easily used for either reference or as a primary driving guidance mechanism.

In general, driver comments were regularly positive and optimistic that the system would benefit their safety and efficiency. The drivers' fast acquisition of the system bodes well for future iterations and eventual deployment. Their suggestions for HMI improvements have been very helpful and will be combined with the objective findings to improve upon the system. Subsequent iterations will include continuous improvements to the HMI.

Acknowledgements

The plow team is headed by the Advanced Highway Maintenance and Construction Technology (AHMCT) research center at UC Davis. Other team members include Partners for Advanced Transit and Highways (PATH) at UC Berkeley, the Western Transportation Institute (WTI) at Montana State University, and the Arizona Department of Transportation (A DOT). This project was sponsored through the Caltrans New Technology and Research Program. Particular gratitude is expressed to the Sierra Snowfighters at the Kingvale Maintenance Center for their insight and hospitality.

Paul Kretz of PATH and Colin Thorne of AHMCT programmed the character and operational displays. Additional thanks are expressed to Benedicte Bougler of PATH, Eli Cuelho of WTI, Mike Jenkinson of Caltrans, and Steve Owen of A DOT for their assistance with data collection.

References

- Dingus, T., McGehee, D., Manakkal, N., Jahns, S., Carney, C., & Hankey, J (1997). Human Factors Field Evaluation of Automotive Headway Maintenance/Collision Warning Devices. *Human Factors*, 39, 216-229.
- Stone, G. (1998). PATH Magnets to Guide AHMCT's Advanced Snowplow for Caltrans. *Intellimotion*, 7(3), 13.
- Yoo, H., Hunter D., & Green, P. (1996). *Automotive Collision Warning Effectiveness: A Simulator Comparison of Text vs. Icons* (Technical Report UMTRI-96-29). Ann Arbor, MI: The University of Michigan Transportation Research Institute.
- Zhang, W., Lasky, T., Jenkinson, M., (1999). Caltrans Advanced Snowplow Program. *Intellimotion*, 7(4), 1-3, 13.

Appendix A – Advanced Snowplow Description

The ASP contains two essential sensing methods, a computer to process the signals, and a HMI. The lateral position was detected by two sets of magnetometers that sensed the magnetic fields generated by magnetic markers embedded along the centerline of the lane every 1.2 m. These magnetometer sets were positioned behind the front wheels and under the rear bumper. Potential forward obstacles were detected with a forward MMW radar sensor mounted on the front of the plow. This sensor was positioned so that it had a clear line of sight when the front plow blade was lowered.

Figure A1 shows an illustration of the ASP and its components. Note the heavy traffic volume. This picture was taken on a Sunday afternoon as many Sacramento and San Francisco Bay area residents were returning from a weekend in the Lake Tahoe vicinity.

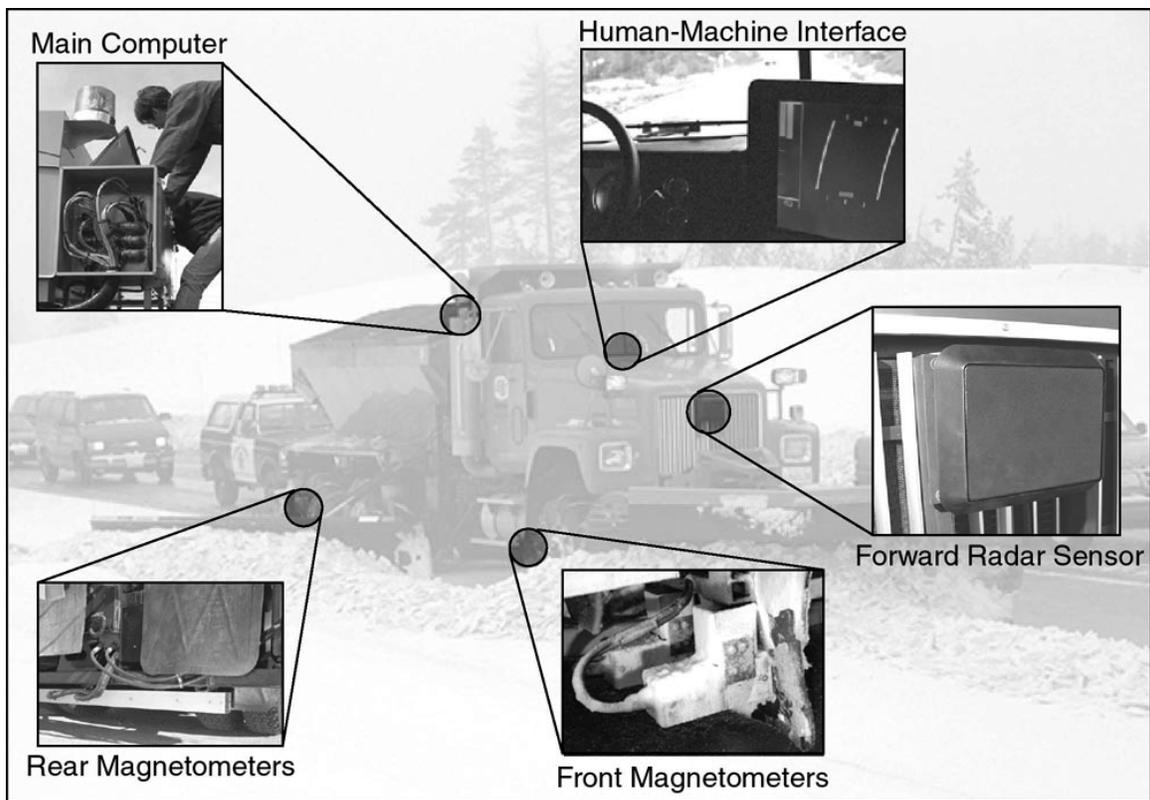


Figure A1. The basic features of the Advanced Snowplow

Appendix B – Arizona Survey

**Advanced Snowplow Evaluation Questionnaire
Arizona Demo**

We would like to ask you some questions regarding your opinion of the driver assist system. We will not be recording your identity and this information will not be associated with you or be used as a means of evaluating your performance. We are only interested in evaluating the system. We may share this with Caltrans/Arizona DOT.

Your participation is voluntary. You are free to refuse to take part. You may refuse to answer any question and may stop taking part in the study at any time. Whether or not you participate in this research will have no bearing on your standing in your job.

How long have you been driving snowplows? _____

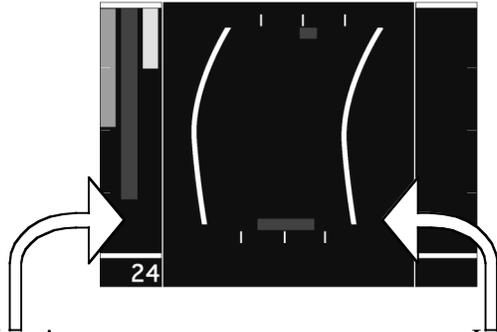
For the following questions, please circle your choice:

- 1) How easy is the system to use overall?
(Very easy) 1 2 3 4 5 (Not easy at all)
- 2) How much do you like the system overall?
(A lot) 1 2 3 4 5 (Not at all)
- 3) If you had more time to practice with the system, would you like it more?
(Yes) 1 2 3 4 5 (No)

How long do you think you would need to become comfortable with this system?

Please answer the questions on the back/next page.

For each *component* (Collision Warning, Lane Keeping):



Collision Warning

How easy is this component to use?

(Very easy) 1 2 3 4 5 (Not easy at all)

How much do you like this component?

(A lot) 1 2 3 4 5 (Not at all)

Comments:

Lane Keeping

How easy is this component to use?

(Very easy) 1 2 3 4 5 (Not easy at all)

How much do you like this component?

(A lot) 1 2 3 4 5 (Not at all)

Comments:

Please draw what you feel would be an ideal display:
