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Mobile Workzone Sign Support

Study SD94-08
Final Report

Prepared by
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Executive Summary

During certain highway maintenance operations, work zones move necessitating resetting the "Flagman Ahead" signs. The Federal Highway Administration's (FHWA) Manual on Uniform Traffic Control Devices (MUTCD) requires signs to be placed between eight and twelve times the posted speed limit. Generally, the signs are placed at ten times the posted speed limit of the workzone the maintenance is being performed upon, i.e. 550 feet on a 55 mph highway. The sign placement is critical to the safety of the workers in that the flagman ahead signs are the first warning to the drivers that they should be prepared to stop. When it is necessary for the signs to be moved, a maintenance worker temporarily leaves his maintenance duties to reset signs.

SDDOT assembled a research technical panel to more clearly define the problem, and decided to build a small remotely controlled vehicle that would move the "Flagman Ahead" sign. The Mobile Sign Support (MSS) would satisfy the safety and productivity concerns in that the flag persons would be operating the sign from their positions not requiring anyone to travel outside of the workzone to reset the stationary signs.

Two MSS's were designed and built, one by each of the two engineering schools in South Dakota. The MSS's are simply operated, powered by two electric motors. The two schools approached the vehicles differently, but the product is essentially the same. SDSU chose a four wheel design, while SDSM&T designed its vehicle with six wheels. Communication between the two schools was encouraged, and once major design choices were made, both schools agreed on certain components for the sake of interchangeability. Electric motors were chosen over a gasoline engine because of ease of use and maintenance, and cleaner operation. The batteries provide power for an 11-hour work day, and are fully charged in one night. They were tested in actual work zone environments three times, and after initial changes in field testing, passed requirements for duration, ease of operation, mobility on uneven terrain and grades.

The MSS's operate well as they were designed. However, while trying to find maintenance units to evaluate them, it became apparent that only a few types of mobile work zones were well suited for the use of MSS's. The workzone must travel at a slow, fairly constant rate. If the rate is too fast, the MSS's may not keep up with the work zone, or if stationary or sporadic, the MSS's may not be utilized at all.

The researchers recommend that, due to the lack of workzones in which mobile sign supports are effective, the South Dakota Department of Transportation should not adopt a policy to use MSS's, but allow their use if desired. The SDDOT should not seek to build more Mobile sign supports until it becomes apparent that consistently slow moving work zones using DOT maintenance personnel are widely used.

Introduction

During certain highway maintenance operations, work zones progress relatively rapidly necessitating resetting the "flagman ahead" signs. The Federal Highway Administration's (FHWA) Manual on Uniform Traffic Control Devices (MUTCD)¹ requires signs to be placed between eight and twelve times the posted speed limit. Generally, the signs are placed at ten times the posted speed limit of the workzone the maintenance is being performed upon, i.e. 550 feet on a 55-mph highway. The sign placement is critical to the safety of the workers in that the "flagman ahead" signs are the first warning to the drivers that they should be prepared to stop. When it is necessary for the signs to be moved, a maintenance worker temporarily leaves his maintenance duties to reset signs.

Several problems arise in the resetting of the signs. First, while the signs are being moved, they are generally not visible to the oncoming traffic. This gives no warning to the driver that he is approaching maintenance activity, leaving the work zone relatively unprotected. The liability here lies in the danger to the workers performing the maintenance. The second issue of concern is the compromised safety of the worker sent to reset the signs. This worker is exposed to traffic outside of the work zone while working on the shoulder in close proximity to oncoming traffic. Coupled with the liability to the worker resetting the signs is the monetary issue of lost productivity while work continues one person short. An added concern comes from the possibility that the signs are not reset at regular intervals. If the signs are not kept within the regulated distance there are definite safety issues along with driver perception problems. If a driver sees a "flagman" sign with no apparent flagman ahead, the dangerous possibility arises that the driver may ignore the signs and not be prepared to stop when needed.

In light of these concerns it was decided to study the use of a small remotely controlled Mobile Sign Support (MSS) in place of the presently used signs. The use of a MSS would alleviate the safety and productivity concerns in that the flag persons would be operating the sign from their positions not requiring anyone to travel outside of the workzone to reset the stationary signs.

Problem Description

According to part VI of the MUTCD, the initial work ahead signs must be placed from 500 feet to a half-mile from the area where work is being performed. It is also required that the flagman ahead signs be placed at ten times the posted speed limit of the work being performed, i.e. for a highway with a speed limit of 55 mph the signs have to be placed at 550 feet of the work being performed. With certain maintenance operations, the work zones move relatively rapidly, covering several miles a day, necessitating frequent resetting of the signs. While the flag person must remain at the beginning of the work zone, a maintenance worker must reset the signs. Figure 1

¹ Part VI of the *Manual on Uniform Traffic Control Devices*, 1988 Edition, Revision 3, Federal Highway Administration, September 3, 1993

shows the layout of a typical maintenance area. This figure shows that the “flagman ahead” signs may be farther than the regulated distance away from the workzone, shown by distance X.

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Figure 1 Workzone with warning sign distance representation

Several problems arise when the maintenance worker leaves the maintenance area. When the worker is resetting the signs, the assigned maintenance is short one worker and productivity is diminished. There are also safety concerns that arise. The worker that is resetting the signs is exposed to traffic outside of the work zone for the time it takes to reset the signs. Also, while the signs are being reset, there is a possibility that the signs are not visible to the traffic. This leaves the traffic unaware of maintenance operations, endangering the maintenance workers.

There are obvious costs associated with the problems stated above. There are also safety and legal concerns. Taking into consideration the future costs of production and operation of the MSS and the costs of lost productivity and liability, a decision was made to produce prototype MSS's.

Objectives

The underlying objective of this project was to provide the maintenance crews with a tool that would increase productivity and the safety of the working environment. The objectives given by the research problem statement are as follows:

1. *To determine FHWA or other requirements that could affect the use of an inexpensive remote control sign.* This objective includes tasks 1 and 2. The literature search revealed nothing regarding crash testing, but the local FHWA office stated that if the MSS is adopted for permanent use, it may have to be crash tested under NCHRP 350 guidelines. The final decision would have to be made when MSS's are manufactured and widely used.

2. *To assess the economic feasibility of building and using remote control signs.* This objective includes tasks 3 and 4. It was intended to provide the technical panel insight into whether MSS's could be built for a reasonable cost. The engineering schools provided preliminary budgets that indicated the vehicles could be built for around \$5000 each.

Costs associated with normal operation of the MSS's were also requested. While performing its duties, the MSS will eliminate the need to remove someone from their maintenance duties to reset signs. Normally, removing the worker from the assigned duties results in a loss of productivity, increasing cost. To be effective, the cost of producing and maintaining the MSS should ultimately be less than the cost of lost productivity and the possible cost of injuries or lives. As shown under "Cost Savings Estimate", it is estimated that the cost of the vehicles would be recovered after 200 workdays.

3. *To develop, test and evaluate a remote control sign support prototype based upon favorable completion of Objectives 1 and 2.* This objective includes tasks 3 through 9. The two engineering schools performed all the tasks requested, including preliminary cost information, design, and final design. Each school had unique ideas for the MSS, so each school built their own prototype. Evaluation of the MSS's was done at several stages, during the development stage, and during actual field evaluations.

The discussion under "Sign Support Performance Evaluation" shows that after solving some preliminary problems, the Mobile Sign Supports performed reasonably well during use in two actual work zones. Usability problems uncovered during these tests revealed that the workzones themselves were not of the type where MSS's could be used to their potential. One workzone was stationary for an hour or more, then moved a distance so the MSS's had to be transported on a trailer. The MSS's were designed to be used in a workzone moving at a slow, constant rate.

4. *To recommend specifications and provide plans for constructing and using remote control signs.* Each school wrote specifications, and plans were provided. Plans are shown in Appendix E and operator's manuals are shown in Appendices C and D.

Literature Search

The first task that was carried out was a literature search to determine if there was an applicable vehicle already in production. If a vehicle were found, an evaluation of its design would be made to determine if it would satisfy the listed objectives. As a result of this literature search, no vehicle was found that fit the desired objectives. There were two vehicles found that were similar to the desired vehicle in operation. These vehicles were excessively complex and too costly for what SDDOT had envisioned. At this time, possible vehicle configurations were also studied.

Cooperative Research

As a result of the concern shown by the Maintenance Standards Panel, action was taken to address these liability concerns. It was decided that a project should be undertaken to study the needs of the MSS and to prepare a design that could be used to manufacture a durable MSS at a reasonable cost. The research was carried out as a collaborative effort between the South Dakota Department of Transportation (SDDOT) Office of Research, South Dakota State University (SDSU), and South Dakota School of Mines and Technology (SDSM&T).

Cooperative research is a new method of research for SDDOT. A number of meetings were necessary with all parties involved to communicate requirements, compatibility and progress. The Rural Development Television Network (RDTN) was used on numerous occasions when face-to-face meetings were not possible.

SDDOT initially set forth constraints and objectives. After some preliminary consultation with the involved parties, some minor changes were made to the list of constraints. Initially, the objective that required the most communication between the working parties was the desire to have as many parts as possible interchangeable between the vehicles prepared by the individual schools. This resulted in the following similar items: electric motors, motor controllers (servo amplifiers), batteries, gear heads (speed reducers), axles, wheels and tires.

In addition to design requirements, the MSS was to be produced for less than \$6000. While it is always tempting to add more features to a product, SDDOT encouraged the design teams to keep the vehicles' cost low.

Requirements

The following requirements were developed to ensure the MSS's would stand up to the maintenance workzone environment:

Operating temperature	32-140° F
Speed range	2-4 mph
Support	48" diamond sign, 24" from ground
Wind loads	80 mph
Dimensions	< 5' wide X 6' long
Operational Duration	12 hours
Operating range	1200 feet
Ground clearance	6"
Max Grade	6%
Vehicle cost	<\$6000
Weather resistant	
Fail safe remote control	

Transported by trailer
Fully charged in 8 hours
Stable on uneven surfaces
Low maintenance
Simple operation

Project summary

It was initially decided that both schools would create separate designs and combine the individual designs into one design using the best technology from both. After the initial designs were completed, however, there were considerable differences. These differences were integral to the global design of each vehicle and it was decided that two different designs would be completed for testing. The purpose of the testing was to evaluate the differences of the designs and make comparisons of the individual results. Making note of the weaknesses that needed attention, a final design was compiled incorporating the most positive aspects of the tests and evaluations. Each university provided reports including design philosophy, drawings, bills of materials and costs. Drawings for both vehicles are shown in Appendix E. Operators' manuals are provided in Appendix C and D.

Vehicle Overview

The general differences of the two designs were in the frame layout, electronics, and the radio controls. The frame of SDSU's vehicle was made of C-channel aluminum while SDSM&T's frame was made of two-inch square steel tubing with 1/4 inch wall. The electronics differed in SDSU's use of a microprocessor and homemade radio and encoder/decoder system to control the servo amplifiers. They also used a tachometer on each of the motors for feedback control with the servo amplifiers (Appendix B). SDSM&T used a similar servo amplifier to control the motors. For simplicity of design, SDSM&T did not use a microprocessor or tachometers. SDSM&T bought an industrial remote control unit from Futaba while SDSU initially designed and built their own remote control unit, which if successful, could have reduced the cost considerably and provided more versatility. Unfortunately, the SDSU radio control unit required significant work at the time of testing because the receiver could not be made to work with the decoding circuitry. Consequently another Futaba industrial radio control unit was purchased (Appendix A). As a result of this purchase, the decoding electronics and the microprocessor were not needed in SDSU's vehicle. A 24V power supply was used to power the radio receiver and servo amplifier in both vehicles.

There were some similarities between the two initial designs. Both designs used two identical 90 VDC brush-type motors. Eight deep cycle 12 V batteries were used to provide the 96-volt operating current. The motors drive sprockets and chains through 20:1 worm gear reducers. Each motor drives one side of the vehicle. The vehicles steer by reversing the wheels on the side of the vehicle to which the vehicle is to turn. In doing this, it induces a "skid-steer" action similar to a

Bobcat skid loader. This method was chosen over traditional methods by both schools because of its lower cost and simplicity.

Field testing was conducted to gage initial problems encountered with the MSS. The most significant problem encountered was overheating of the servo amplifiers. This problem was rectified with the use of heat sinks and cooling fans. Additionally, there was some concern with confirming proper operation at significant distances. While it is relatively easy to judge the MSS's position with respect the lane and the edge of the shoulder, it is a little more difficult to tell if the MSS is traveling towards the operator. Since testing, a flashing light was added to the MSS to confirm proper operation.

The initial reaction from maintenance workers to the MSS was favorable. It was concluded that there would be certain maintenance activities for which the MSS would be an effective tool. Some of the applications include route and seal of concrete pavement where the cracks are a relatively short distance apart, crack sealing operations and chip sealing operations. The use of the MSS would eliminate the need for a maintenance worker to travel along the shoulder to reset the "flagman ahead" signs. Additionally, the MSS would provide a measure of safety for the maintenance crews.

Crash Test Requirements

Federal regulations do not specifically address the MSS in highway workzones because of the uniqueness of the vehicle. The authoritative source on crash testing, National Cooperative Highway Research Program (NCHRP) report 350, addresses items like light poles, delineator posts, road signs, and guard rails. If these vehicles become widely used in many workzones, the decision to crash test would be made by the Federal Highway Administration.

Initial Design

SDSM&T and SDSU developed designs outlining the frame, major components, and control system. Through discussion between the universities and SDDOT, similar items were identified to facilitate interchangeability between the two vehicles.

The drive system chosen by both schools favored electric motors over gasoline engines because of cleaner operation and simpler maintenance.

96V brush type DC motors were chosen over brushless motors because of its lower cost and simplicity of design and control. Brushless motors have the advantage of higher efficiency and performance, but the cost is much higher than brush motors. A 96V motor was chosen over lower voltage motors to produce the torque necessary for climbing grades and negotiating rough terrain. The disadvantage is that eight 12V batteries are required, bringing the vehicle weight over 700

pounds. But the high weight appears to be necessary to withstand high wind loads on the traffic sign, according to design calculations².

SDSU and SDSM&T produced a preliminary design for cost estimates. An initial parts and construction budget of \$6000 was set up. Both schools determined that an MSS produced in volume could be manufactured for approximately \$5000.

The project yielded two individual vehicles, one prepared by SDSU and one prepared by SDSM&T. Two vehicles were produced in order to evaluate different design characteristics. Discussed below are the design characteristics of the individual vehicles.

SDSU's Vehicle

The vehicle prepared by SDSU was constructed of aluminum because of its lightweight and resistance to corrosion. Steering was carried out using a skid steer method. Two 3/4 HP motors, one for each side of the vehicle, propelled the vehicle. The motors were brush-type 90 VDC driving the wheels through 20:1 gear reduction. The output shaft of the gear reduction was direct-coupled with the axles on the front of the vehicle (Figure 2). The rear wheels were driven through a sprocket and chain assembly. Initially the reduction amount of 20:1 was chosen to achieve a driven speed of approximately four miles per hour. During testing, this reduction produced adequate speed, but was suspect in the amount of torque that it delivered in turning and hill climbing operations. In order to have enough torque to operate in an acceptable manner, a higher reduction ratio was needed. Considering the physical layout of the drive train, a new gear head would have to be purchased or the motor and gear reduction repositioned allowing an additional reduction through a sprocket and chain assembly.

The SDSU vehicle utilized eight 12 V deep cycle marine batteries to provide electricity for the motors. The motors were controlled with two servo amplifiers. Tachometers were installed on the motors to provide closed loop control of the motors, promoting even tracking. The servo amplifiers received motion commands from the remote via a microprocessor through encoding/decoding circuitry. The initial remote control system was designed and built by SDSU. Due



Figure 2 SDSU's vehicle, without cover.

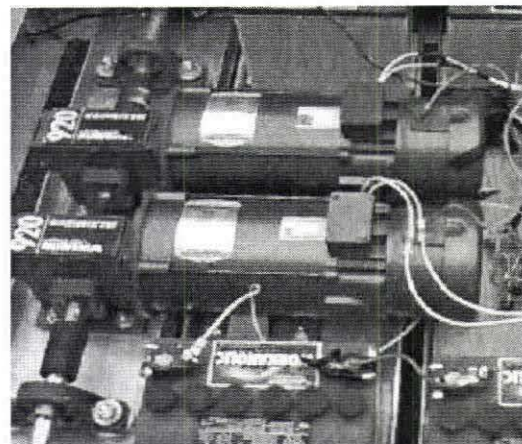


Figure 3 SDSU's motors and reducers.

² *Mobile Sign Support Project*, Larson, Miller, Riley, & Romberg, South Dakota School of Mines and Technology, May 3, 1995

to the complex nature of radio technology and time limitations, the remote control system could not be made operational in time to test the vehicles. Consequently, an industrial radio transmitter and receiver were ordered from Futaba to replace the original SDSU unit. This eliminated the need for the encoding/decoding circuitry and the microprocessor.

A charging port was added by DOT after delivery. An access panel was also added to the cover of the vehicle, exposing the charging port and the on/off switch. Plans for this vehicle are shown in Appendix E.

SDSM&T's Vehicle

The vehicle prepared by SDSM&T was constructed of steel and traveled on six wheels. As with the SDSU vehicle, two 90 VDC brush-type 3/4 HP motors were used, one operating the wheels on either side, to move the vehicle and turn it in a skid steer fashion. The motors initially powered the wheels through a 20:1 gear reducer, and a chain and sprocket assembly to the center axle, which in turn drove the outboard wheels. The same problem with the inability to turn and climb hills was encountered. As a result of the physical layout of the drive train, it was possible to achieve a greater reduction by replacing the initial driven chain and sprocket assembly. These sprockets were replaced and a reduction of 33.33:1 was achieved. This rectified the maneuverability problem.

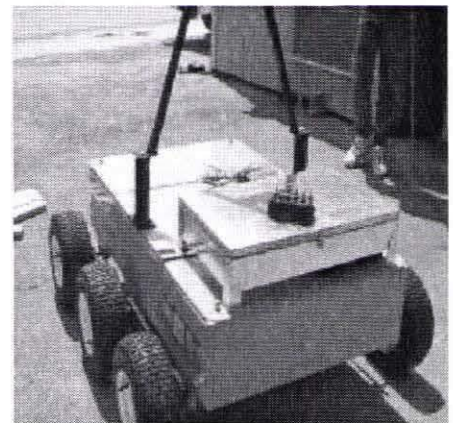


Figure 4 SDSM&T's vehicle.

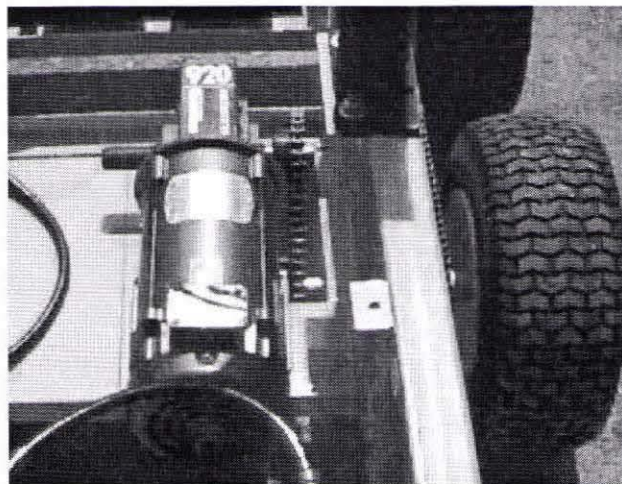


Figure 5 SDSM&T drive train and sprocket assembly.

SDSM&T also used eight 12 V deep cycle batteries to supply the motors. SDSM&T used the Futaba industrial remote control unit from the beginning. They also used two servo amplifiers to

control the motors, although they opted not to use the tachometers and operate in a constant voltage mode to assure proper tracking.

During the evaluations, both vehicles used a Futaba industrial transmitter/receiver unit for the remote control duties of the vehicle. Initially, the range achieved by the transmitter was inadequate. A ground plane was added to the antenna, increasing the operating range to approximately 800 feet—still far short of the 1200-foot design criteria.

During initial testing, a problem with overheating was encountered with both vehicles. At a temperature of 149°F the servo amplifiers shut down, allowing no commands to be given to the motors. Heat sinks in SDSM&T's vehicle and cooling fans in SDSU's vehicle were added to ensure that the servo amplifiers would operate under their temperature threshold. A DC/DC converter that also powered the receiver powered these. Proper mounting and heat sinking can eliminate the fans.

SDSM&T's vehicle did not come to DOT with provisions for charging the batteries. DOT staff added a charging port, shown in Figure 6, and an on/off switch accessible from outside the vehicle. A flashing light was added to indicate to the operator when the vehicle is moving. The light is connected across the motor and illuminates whenever the motor is energized. A small circuit board was added with potentiometers to adjust motor speed when necessary. Plans for this vehicle are shown in Appendix E.

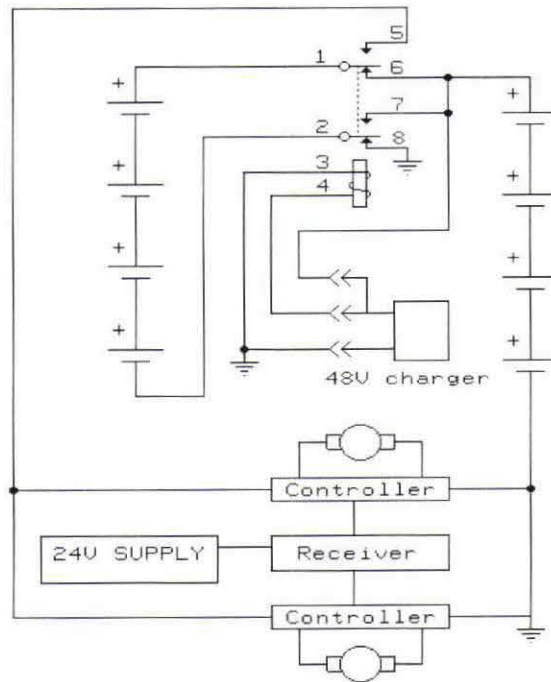


Figure 6 MSS circuit, in charge position.

Preliminary Testing

Preliminary testing was carried out on the MSS's to evaluate the initial designs in the summer of 1995. A few shortcomings were discovered with both vehicles. The vehicle prepared by SDSU required a new remote receiver/transmitter unit because the provided unit did not function. These problems were rectified when a Futaba industrial remote control unit was purchased to replace the original unit and cooling fans were installed to cool the servo amplifiers that control the motors. The SDSM&T vehicle suffered bent axles sustained as a result of impacts, i.e. traveling over obstacles too quickly. Action was taken to reduce the vehicle's speed by increasing the drive ratio, which consequently provided more torque to the wheels. A change that was made to both

of the vehicles to reduce speed was the addition of a second slower speed that could be accessed from the remote transmitter unit. This slower second speed was installed in order to ease the traversing of obstacles and the loading of the vehicles onto a trailer for transport. Stronger axles were also added.

Sign Support Performance Evaluation

Having been tested in parking lots, the sign supports were evaluated on only two active work zone environments. The field testing was carried out on workzones that were performing routing and sealing of concrete pavement. In one situation, a relatively large distance separated areas of the highway requiring work. Because of this, the MSS was positioned in one spot for the duration of the

Figure 7 SDSM&T vehicle in the work zone.

routing operation and upon completion of the routing was moved ahead from 1/2 to 3/4 of a mile at a time. This necessitated the loading of the MSS on to a trailer to transport it to the next problem area. Although the MSS was not designed for this type of work, it allowed the flagman ahead signs to be kept at the regulated distances to the workzone. If the MSS had not been used, the flagman ahead signs would have stayed at the original two mile spacing. This maintenance project was obviously not a good use of the MSS's because of the distance involved between work areas.

It is important that the maintenance unit have enough personnel available to allow the work zone to move at a constant rate. Otherwise the work zone is stationary until all work is done, then moves to the next position which may be 1/2 mile or more down the road.

During October 16-18, 1996, falling weight deflectometer testing was done on a 4000-

Figure 8 Futaba radio transmitter.

foot section of new fiber concrete seven miles south of Onida on US83. Joints were 15 to 25 feet apart and a test would be performed on each joint and near the center of each panel. The work zone was moving .25 miles per hour on the average. The flaggers were Darrin Charleson and Les Brown from Data Inventory. They each operated a MSS for over a day, then traded MSS's. Below is a list of concerns for the MSS's, based on their comments.

Controls

The flaggers had to hold a stop paddle, a radio, and the control transmitter. This was cumbersome, and could be improved by providing an easier method of attachment for the radio and possibly using a remote microphone attached to the flagger's clothing. Providing paddles with a clip would prevent the flagger from having to drop the paddle to the ground to talk on the radio or operate the transmitter.

Figure 9 SDSU's MSS vehicle in the work zone.

Both Darrin and Les thought the control transmitter was easy to use and recommended no changes.

Loading and Unloading

Flaggers had limited opportunity to load and unload MSS's from the trailer, but thought it straightforward and did not recommend changes.

Charging/Battery capacity

The flaggers did not place the MSS's on chargers, and could not comment. The MSS's were charged for 15 hours after the first day of use. They operated for an 8 hour day and were not charged that evening. The next day, they operated for about 3 hours before losing power. The two vehicles lost power within one hour of each other, and had about 11 hours of capacity.

Maneuverability and Speed

The flaggers agreed that the 6-wheeled vehicle was more maneuverable and steered more easily. It also handled rough terrain and the berm on the shoulder created during recent reconstruction that paralleled the highway.

Darrin observed that the 4-wheeled vehicle seemed to have better

Figure 10 Flagman using mobile sign support in a work zone.

traction, although it wasn't as maneuverable as the 6-wheeled vehicle. The 6 wheeler was geared lower than the 4 wheeler, and consequently moved more slowly. The faster response time on the 4 wheeler made it easier to control at a distance because movement was obvious. The 6 wheeler made it difficult to determine movement because of its slow speed. Darrin thought a speed somewhere between the two vehicles would be ideal.

Both vehicles climb onto the roadway from most typical ditches at any angle without a problem.

Distance

It was difficult to determine distance from the flagger to the vehicle. Fortunately, the distance between telephone poles was known, and the MSS was positioned using them for reference. The MSS's were initially positioned 550 feet away from the flagger. At that distance, the vehicles are difficult to position because they are hard to see. When the distance grew to over 600 feet, the vehicles would not respond at all because they were out of range. Earlier tests revealed a range of 1000 feet. Also, a low cost method of determining distance would be desirable. Unfortunately, methods available for doing this now would add considerable cost to the vehicle. Overall, the flaggers thought the MSS's behaved in a predictable way, and made the job of keeping the signs at the correct distance easier.

Cost Savings Estimate

In addition to making a workzone safer for workers, the MSS was expected to save money because the worker who would otherwise be moving signs several times a day could do his normal job, while the flagger operated the MSS.

On average, a workzone may move at a rate that requires that signs be reset ten times in one working day. Workers normally move signs when they are 2 miles from where they are supposed to be. Signs have to be moved once an hour. Moving the signs takes about 15 minutes and requires a worker to travel about 8 miles, depending on the length of the work zone, to move the signs on both sides of the work zone. Assuming that each time that the signs have to be moved at a combined worker time and equipment cost of \$5, moving signs costs \$50 per day. The \$10,000 cost of two MSS's used in a typical workzone, would be recovered after 200 workdays. From this standpoint, the MSS is monetarily feasible. There is also an added advantage of reducing possible liabilities associated with sending workers along the shoulder of the highway to reset the signs.

The cost of one night's recharging, at 4.3 cents per Kilowatt-hour, is 17.2 cents.

Vehicle Cost

Itemized parts list for each of the Mobile Sign Supports are shown in Appendix F. These lists include only parts and labor used in the final version of the vehicle. Parts purchased but not used in the vehicle are not listed.

The SDSU vehicle had a final cost of \$5214. SDSM&T's vehicle cost a total of \$5580.59. These costs are for prototype vehicles that are unique. If they were ever to be produced in quantity, the prices could be reduced by purchasing parts in quantity, improving manufacturing methods, and optimizing the design.

Final Design

As a result of the testing done, the six-wheel design was found to be better suited for use in a workzone than the four-wheel design. During testing, the initial reduction ratio of 20:1 didn't produce adequate torque, but a ratio of 33.3:1 resulted in a speed so slow that the operator had difficulty determining from a distance whether the vehicle was moving. A ratio of 25:1 implemented on the six-wheel design may prove to be ideal. The electronics would be placed inside the vehicle, unlike the prototype. Aluminum channel and sheeting in the prototype was heavier and stronger than necessary, and can be made lighter now that the exact location of components is known. Also, the addition of kill switches on the front and back of the vehicle would shut down power if the vehicle were to come in contact with an obstacle. Some form of distance measuring system could be added if it would not add considerably to the vehicle cost. A gage or meter for accurately displaying the condition of the batteries should also be included in the production vehicles.

Should the SDDOT determine that Mobile Sign Supports are needed in mobile workzones, a manufacturer will have to be found. There was no investigation regarding who might build these vehicles. However, a manufacturer of golf carts at one point indicated he would be able to build them. There were no formal discussions regarding the actual fabrication or costs. The design drawings for each of the vehicles are shown in Appendix F.

Cooperative Research Evaluation

Each university did a fine job of building their mobile sign support. Unfortunately, it is difficult to maintain continuity among students working on the project across several semesters. The senior students, who often contribute the most to the project, may graduate before project completion. Time is lost trying to inform new students of the project and progress to date.

Another problem experienced in cooperative research among universities, is the urge for students and faculty to view the project as a competition between the universities, rather than a

cooperative effort. This resulted in their resistance to communicate with each other on issues that required cooperation, such as choosing compatible components. When more than one entity is involved, it is critical that all participating members meet face to face at least once in the first stage of the project and as often as is practical thereafter. These initial meetings should instill the teamwork ethic as well as promoting ideas. In this case, it may have reduced the tendency for competition between the researchers. After the initial meeting, relationships are formed allowing following RDTN meetings and teleconferencing to be more relaxed and productive.

Conclusions

The mobile sign supports performed well in the field tests. They did well in the work zones that moved at a steady pace. With a few more refinements, such as extending the range, the MSS is a viable tool to save manpower and enhance safety.

When this study was initiated, it appeared that the type of workzone where mobile sign supports would be useful was widespread. A workzone moving 2 to 10 miles in a day would be ideal for the use of mobile sign supports. Finding this type of workzone for MSS evaluation, however, was difficult. As stated earlier, SDDOT has reduced its workforce during 1996 and increased the number of contract maintenance jobs. If there are not enough people to do work operations simultaneously, the workzone is stationary for a time. In the case of a rout and seal job, personnel rout the cracks in the workzone, and then seal the cracks, consuming more time. The entire workzone then moves to the next section of road. Ideally, with the proper number of workers, the routing can be done with the sealing operation close behind. In this way, the entire workzone moves slowly along at a fairly consistent rate. This situation is where the mobile sign supports are best suited.

Recommendations

Due to the lack of workzones in which mobile sign supports are effective, the South Dakota Department of Transportation should not adopt a policy to use MSS's, but allow their use if desired. The SDDOT should not seek to build more Mobile sign supports until it becomes apparent that consistently slow moving work zones using DOT maintenance personnel are widely used.

Appendix A - Radio Control

Appendix B - Motor Controllers

Appendix C - Operator's Manual for SDSM&T's Vehicle

Appendix D - Operator's Manual for SDSU's Vehicle

Appendix E - Design Drawings

Appendix F – Bills of Materials