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Maintenance Work Zone Safety

An Unpublished Final Report

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This report is being distributed to the sponsors of the Strategic Highway Research Program, AASHTO, the Transportation Research Board, and the state highway agencies for the limited purpose of advising those recipients of the preliminary results of the research that was conducted under SHRP Project H108, Maintenance Work Zone Safety.

Because some of the research results describe designs of potentially patentable inventions and SHRP's policy permits a contractor who conceives of a patentable design to secure a patent for that design, any information on the design of specific devices should be treated as proprietary and confidential. It is for your information only and it should not be further copied or used in any way which affects the rights of the contractor.

Preface

This final report for the Strategic Highway Research Program contains illustrations and descriptions of a number of devices designed to protect highway maintenance workers. Since project H-108 was the first phase of a two-phase effort, these devices have not been tested. The authors of this report and the Strategic Highway Research Program do not recommend use of the devices at this time. A follow-on effort (project H-109) will evaluate and test the devices to determine their appropriateness and safety for highway use.

Acknowledgments

Data reported here were gathered from several State highway departments and one tollway authority. Accident data were received from States of Iowa, Nebraska, Washington, Missouri, California, Texas, Florida, and Virginia. Accident data was also received from the New York State Thruway Authority which also permitted videotaping of their maintenance operations. Other States that permitted videotaping include Missouri, Minnesota, New York, California, Florida, Ohio, Texas, and Virginia.

Over 300 companies furnished information on maintenance equipment. The eleven companies listed in Table 16 furnished time and information for the industry visits.

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Summary

Highway maintenance work is one of the most hazardous occupations in the nation. The growing need to repair existing pavements and structures while maintaining traffic flow makes maintenance work-site safety of increasing concern to workers and highway users. The cost of setting up and maintaining traffic controls at work sites has risen rapidly. Where work sites are short-term or mobile, stationary devices are not practical and good alternatives are not available. If highway organizations are to meet the need for flexibility, mobility, economy, and safety in work-site traffic controls, new and effective technologies are needed.

Most maintenance activities are short-term, moving or mobile. The most common definition of short-term work is an activity that requires traffic control, takes less than one period of daylight, and is not done at night. (However, more maintenance work is now being done at night, and night operations should certainly be considered when developing new devices.)

SHRP Project H-108 was a two-year, four task effort whose objective was to develop new and more effective ways to protect workers in maintenance work zones from the hazards of nearby traffic.

Concepts for new devices were sought via an international design competition that asked for innovative ideas in ten challenge areas. The ten design challenges were chosen based on observed accident and operational problems in current maintenance work zones and an industry survey of existing equipment and materials used in highway maintenance.

One hundred twenty-six proposals were received covering 28 states and three foreign countries. Thirty-seven concepts were awarded cash awards totaling $25,000. The project staff and expert task group (ETG) also conceived seven staff ideas. Of these forty-four concepts, forty were researched and designed in the last task of the project. A feasibility study was conducted for one other concept, and three concepts were not pursued.

The concepts were designed in seven groups or study areas. The seven study areas were:

* Barriers
* Warning Devices
* Rumble Strips
* Delineation Devices
* Lighting Devices
* Signs
* High Potential High Risk Feasibility Study

The design effort resulted in abandoning or combining some concepts as well as design of a total of 24 devices. The devices that were designed in each study area are shown in Table 1.

Table 1

H-108 Devices Designed

Study Area	Devices	Page
Barriers	S.CAI Barrier	104
	Personnel Protection Trailer	110
	Movable Barrier End Terminal	112
	Aluminum Can Truck Mounted Attenuator	118
	Salt Spreader/TMA Interface Structure	120
	Portable Crash Cushion	123
Warning Devices	Ultrasonic Detection Alarm	131
	Infrared Intrusion Alarm	139
	Pressurized Pneumatic Tube Alarm	145
	Queue-Length Detector	147
Rumble Strips	Traveled Way Rumble Mat	165
	Traveled Way Speed Bump	172
	Edge of Traveled Way Rumble Stripe	174
Delineation Devices	Moving Taper	183
	Portable Soft Barricade System	203
	Direction Indicator Barricade	211
	Opposing Traffic Lane Dividers	227
Lighting Devices	Snow Plow Floodlight	240
	Snow Plow Blade Markers	248
	Diverging Lights	273
Signs	Flashing STOP/SLOW Paddle	298
	Flagger Gate	312
	Portable Sign and Stand	331
	Truck Mounted Message Box	337

The feasibility study of the automatic guided warning vehicles found that the concept of a robot type vehicle to be used as a sign caravan or shadow vehicle is feasible. The details of this study are given in Appendix K.

2

Introduction and Research Approach

Research Problem Statement

Highway maintenance work is one of the most hazardous occupations in the nation. The growing necessity to repair existing pavements and structures while maintaining traffic flow makes maintenance work site safety of increasing concern to workers and highway users. The cost for setting up and maintaining traffic controls at work sites has risen rapidly. Where maintenance work sites are short-term or mobile, stationary worker protection devices (barriers) are not practical and good alternatives are not available. Frequently pavement maintenance requires occupancy of more than one lane or temporary exposure in multiple lanes. Reduction of this exposure space or time could significantly reduce accidents and improve capacity. If highway organizations are to meet the need for flexibility, mobility, and economy in effective work site traffic controls, new technologies are needed.

This study identified existing maintenance procedures and safety problems and developed new devices (such as effective portable barriers, portable energy attenuation devices, automated traffic warning devices, portable rumble strips, and robots) and the appropriate traffic control systems and maintenance operating procedures to employ them effectively.

This contract (SHRP Project H-108, "Maintenance Work Zone Safety") is Phase One of a two-phased approach. Phase One included an evaluation of the traffic control/worker protection needs of maintenance work zones, work zone traffic control measures, protective/warning systems, etc.; and maintenance equipment, materials, and procedures. It addressed time and space occupancy required to implement traffic control/worker protection and to effect roadway repairs. This review was used to identify and justify innovative approaches to reduce or eliminate maintenance worker exposure. A Phase Two contract, SHRP Project H-109, "Maintenance Work Zone Safety Devices Development and Evaluation," will be awarded at the completion of H-108 to construct and test devices conceived during this project.

Research Objectives

The objective of this research is to develop new and more effective ways to protect workers in short-term maintenance work zones from the hazards of nearby traffic. New devices that reduce the frequency or severity of accidents involving maintenance workers will be conceived, designed, and evaluated.

Research Approach

The project was conducted in four tasks over a two-year contract period. Task 1 furnished a framework from which new devices were conceived and evaluated.

This framework classified existing conditions in maintenance zones, and the safety problems being experienced, (especially those involving workers). Task 1 was subdivided into three subtasks:

Subtask 1A - Maintenance Safety Problems

Subtask 1B - Operational Conditions

Subtask 1C - Safety Impact Assessment

Accident, operational, and industry data were collected. An accident data base of 324 maintenance work zone accidents were collected and analyzed. Ninety-six hours of maintenance operations were videotaped, vehicle speeds and conflicts with traffic were observed. Eleven industry visits were made in order to determine the state-of-the-art in maintenance work zone equipment and to ensure that ideas and devices that already exist were not reinvented during the design competition.

<u>Task 2</u> involved the development of a number of design challenges addressing areas needing improvement. Task 2 was divided into the following three subtasks:

Subtask 2A - Define Areas for Improvement

Subtask 2B - Distribute Design Challenges

Subtask 2C - Evaluate Device Designs

These design challenges were used as the basic categories for the Task 2 - Design Competition. The purpose of the design competition was to focus nationwide attention of the technical community on an effort to develop innovative devices and methods that will ameliorate maintenance work zone safety problems. The rules of the competition and background on each design challenge were published in a prospectus. This prospectus was mailed to over 600 persons.

By December 15, 1988, the final date for accepting proposals, 126 proposals were received. These proposals were reviewed and rated by the project staff and an expert task group (ETG).

The purpose of Task 3 was to conduct two meetings of an expert task group (ETG) and to document these meetings and the design competition results in an interim report to SHRP. This report contained recommendations on what devices to develop during Task 4.

During Task 4 recommended devices were further evaluated and those found feasible were designed and are described in this final report. Prototype plans were drawn for each feasible device and will be used to fabricate designs during the H-109 contract.

3

Findings

Safety Impact Assessment

This section discusses the findings of the Task 1 accident studies, operational studies, and industry visits. The findings of the two expert task group meetings are also discussed.

Accident Study Findings

1. Maintenance workers are injured both while pedestrians on the roadway and as vehicle occupants.

2. Vehicle accidents such as snow plow and sweeper accidents comprise the largest number of accidents but pedestrian worker accidents are much more severe. For example almost every flagger accident involves an injury.

3. Vehicle accidents are almost all rear-end or over taking accidents.

4. The data base of accidents from six States and one toll authority does not support the contention of 500 maintenance workers being killed each year. The actual number is difficult to determine because maintenance accidents are often not coded as work zone accidents. The number of workers fatally injured each year is estimated to be on the order of 25-50.

5. Protective or traffic control vehicles are effective in shielding work vehicles and workers from errant vehicles. These vehicles should be equipped to minimize injury to the truck driver and the impacting motorist.

6. Operations in the traveled way involve a higher percentage of maintenance work zone accidents than operations on the shoulder or roadside. Safety would be served if workers, vehicles, and equipment could be moved to the shoulder or beyond. However fatalities were observed with people and vehicles on the shoulder and roadside and occupancy of these areas should be kept to a minimum.

7. Moving operations experience more accidents, but accidents involving mobile and short-term stationary operations are more severe.

8. On road moving activities represent 35.8% of maintenance work zone accidents but only 14.7% of the maintenance hours are spent in these activities. On road stationary operations represent 32.4% of the maintenance accidents and 29% of the total hours spent. Off roadway activities represent 9.0% of the accidents but 28.6% of the time spent.

9. Rural areas may be more hazardous for maintenance due to higher vehicle speeds and the difficulty of warning of operations that cover a long section of roadway, and because the large majority of roadways in the U.S. are in rural areas.

10. Two-thirds of the maintenance work zone accidents occurred between 9 a.m. and 4 p.m.

11. Some fatal accidents involve motorists who are unable or unwilling to react to traffic control devices. These accidents point to the need for barrier and protective devices.

Operational Study Findings

Typical maintenance activities were videotaped in eight States. Serious incidents, conflicts and erratic maneuvers and radar speed measurements were recorded from a total of 91 studies and over 96 hours of maintenance activity.

Findings from the studies are noted below:

1. Serious conflicts or near accidents were observed in 22 of the studies. Twenty-nine separate incidents were observed. Seven of these incidents involved flaggers or policemen controlling traffic. Ramps on freeways were involved in six of the incidents, and arrow panel operation or confusion with the arrow signal was involved in four incidents.

2. Conflicts were noted for seven types of maintenance operations. These operations in order of highest conflict rates were:

    1. Guardrail repair;
    2. Sweeping;
    3. Attenuator repair;
    4. Tie between pothole patching and roto milling;
    6. Utility work; and
    7. Pavement and asphalt repair.

3. Erratic maneuvers of single vehicles were also noted. The top seven operations by erratic maneuver rate are:

    1. Pavement and asphalt repair;
    2. Utility work;

3. Guardrail repair; and

4. Tie between attenuator repair, pothole patching, crack sealing, and snow removal.

4. Speed measurements were made during 37 of the operational studies. Speeds were recorded for cars and trucks on the approach and near the work area. Some of the studies showed that speeds were equal or higher near the work area compared to the approach. Asphalt overlay jobs had speeds that were up to 27 mph below the speed limit. For a crack sealing operation car speeds were only reduced 5 mph from the approach to the work area and truck speeds were only reduced 3 mph. Many of the studies showed that trucks were travelling slower on the approach, but reduced their speeds less near the work area.

5. Observation of flagging operations revealed that flaggers often stand with their backs to traffic or sideways in order to communicate with other flaggers. Present flagger vests are not normally visible when the flagger is standing sideways.

Industry Visit Findings

Some general conclusions that can be drawn from the industry visits are given below:

1. Larger companies in general are not interested in the design competition.

2. Most companies interviewed expressed concern about patent rights. In all cases, the companies would want to keep the patents on any patentable products they developed.

3. Most of the industry people interviewed appreciate the dangerous nature of highway maintenance because they had first hand experience with this type of work.

4. Products and practices already exist that can help make maintenance work safer than it presently is, but are not widely used or recognized.

5. Motorists usually do not obey work zone speed advisories.

6. Night work is more dangerous because of drunk drivers and decreased visibility.

7. In some cases, motorists act in an almost hostile fashion towards maintenance workers.

8. Worker safety in traffic is sometimes a lesser concern for equipment manufacturers compared to product liability.

9. Work zones can be especially difficult for large trucks to negotiate, either because of abrupt speed changes, rapid lane closures, sharp turns, or severe lane restrictions.

10. In the field , work zone products are often misused or misapplied by workers.

Expert Task Group Assessment

Based on the above findings and a meeting of an expert task group where these results were discussed, ten design challenge areas were formulated in four basic categories. The four categories were based on exposure reduction and 1-2-3 system for increasing worker safety.

First give adequate warning to drivers to make them aware of the work zone ahead. Secondly warn workers if a vehicle is encroaching into the work area.

Lastly, if vehicles encroach provide barriers and other protection for workers.

The final list of design challenges are shown below:

Category 1 - Improving Drivers' Understanding of the Maintenance Work Zone

Area 1A - Improved Traffic Control Techniques and Devices for Advanced Warning and Transition area.

Area 1B - Alleviation of Rear-End Collisions Between Traffic and Snow Plows or Salt Spreaders.

Area 1C - Improved Flagging Techniques and Devices.

Category 2 - Effective Warning to Workers

Area 2 - Warning Devices for Maintenance Workers.

Category 3 - Effective Protection for Highway Workers

Area 3A - Protection of Pedestrian Maintenance Workers on the Roadway During Mobile Maintenance Operations.

Area 3B - Methods or Devices to Eliminate or Minimize Injury in Rear-End Collisions with Maintenance Vehicles.

Area 3C - Improved Safety and Protective Clothing for Pedestrian Maintenance Workers.

Category 4 - Open Category

Area 4A - Techniques, Tools, Equipment, or Materials to Remove, Substitute, or Lessen Exposure of Pedestrian Maintenance Workers on the Roadway.

Area 4B - Non-Accident Methods to Quickly Evaluate Traffic Control Devices, Lane and Route Guidance, and Training.

Area 4C - Devices for Special Maintenance Operations included Nighttime or Emergency Work.

Design Competition

The purpose of the design competition was to focus nationwide attention of the technical community on an effort to develop innovative devices and methods that will ameliorate maintenance work zone safety problems. The rules of the competition and background on each design challenge were published in a prospectus. This prospectus was mailed to over 600 persons.

By the due date of December 15, 1988, 126 proposals were received. The proposals represented a total of 28 States and three foreign countries.

Each proposal was rated using the following six criteria, feasibility, usability, applicability, expected effectiveness, possible tradeoffs, and cost. Each of the criteria is defined as follows:

Feasibility - the level of technology involved in the concept. It ranges from presently unavailable technologies to technologies in common use.

Usability - a concept's ease of use by maintenance workers. It ranges from unusable concepts because of the education, experience, or expertise required; to concepts that require no special training or experience to use.

Applicability - how well the concept addresses the problem area. It ranges from concepts that can not be applied to the problem area because of roadway design constraints, temperature constraints, etc.; to concepts that can be applied to the problem area under all reasonable conditions.

Expected Effectiveness - involves the concept's ability to potentially mitigate injuries or deaths of maintenance workers. It ranges from a concept that neither saves lives nor reduces the number of severity of injuries of maintenance workers, to a concept that reduces 100% of the injuries and deaths of maintenance workers for the problem area.

Possible tradeoffs - the level of undesirable side effects produced by a concept. It ranges from tradeoffs that disqualify a concept's use, to no tradeoffs which would adversely influence the concept's use.

Cost - the life cycle cost of the concept including development, fabrication, and maintenance costs of the concept. It ranges from a cost so high as to disillusion any potential buyers, to a low cost.

Proposals were rated by assigning a score of 0 to 4 to each of the six criteria and then multiplying the six criteria scores. (Details of the rating procedure are given in Appendix D.) Proposals were rated by project staff and ETG members.

A total of 37 cash awards were made to the top ranked proposals. Cash awards varied from $2,000 to $500.

The project staff and ETG also brainstormed a number of concepts during the project. Most of these ideas were in the barrier design area which had few design competition proposals.

The 37 design competition award winners, and seven staff and ETG ideas were grouped into eight study areas for the Task 4 design effort. These 44 proposals are shown in Table 2 grouped by study area.

Device Design and Implementation

The overall goal of the Task 4 design effort in each of the study areas was to develop devices that can be commercially provided for use by maintenance forces in the U.S. or any foreign country. The tasks seen as necessary to meet this goal were specified for each study area.

Table 2

Concept Proposals By Task 4 Study Area

Area 1-Barrier Design

855 - Tote Trailer for Sand Barrels
317 - S.CAI Barrier
SI1 - Personnel Protection Trailer
SI2 - Movable Barrier End Treatment
SI3 - Reusable TMA
SI4 - Snow Plow TMA Interface

Area 2 - Warning Device Prototypes

506 - Work Area Intrusion Alarm
810/807 - Personnel Early Warning System
843 - Life Saver
739 - The LookOut
108 - Early Warning Device
692 - Infrared Errant Vehicle Detector
912 - Infrared Queue Length Detector
670 - Portable Protective Warning System
270 - Buffer Zone Alert System

Area 3 - Rumble Strip Fabrication and Testing

118 - Work Zone Rumble Strips
933 - Portable Traffic Warning Speed Bumps
187 - Portable Rumble Mat
287 - Safe Speed Reduction Mat

Area 4 - Delineation Device Fabrication and Testing

310 - Opposing Traffic Lane Dividers
002 - Direction Indicator Barricade
990 - Fiber Optic Caltrop
579 - Retractable Transition Device
941 - Portable Soft Barricade System
156 - Delineator Hose
SI6 - Moving Taper

Area 5 - Lighting Device Testing

068 - The Guiding Light
172 - Snow Plow Blade Markers
049 - Attentive Signing Device
918 - Police Light Assembly
319 - TROTAR
SI7 - Diverging Light

Table 2 (concl.)

Area 6 - Sign Fabrication and Testing

032 - Portable Sign Stand and sign
999 - Flow through Stop and Slow Paddle
161 - Flashing Stop/Slow Paddle
SI5 - Flagger Gate
467 - Truck Mounted Message Box
875 - Alternate Merge Signs

Area 7 - High Potential-High Risk Concept Development

890 - Automatic Mobile Warning Vehicles

Area 8 - Testing of Promising Concepts

832 - Brooks Pavement Marking Device
654 - 3 Way Dump Body
898 - Helmet Liner

The tasks included both H-108 efforts and H-109 efforts. In general the H-108 efforts were to develop prototype plans of the various devices. Due to budget constrains and the high risk and cost of the automatic mobile warning vehicles, only a feasibility study of this concept was conducted. Also, the concepts in Area 8 were not pursed due to budget constraints.

The descriptions of the H-108 efforts in each study area are detailed in Appendices E-K. The design efforts resulted in abandoning or combining some concepts, as well as the design of 24 devices. The final status of the design of each device is shown in Table 3.

The level of detail of the prototype designs vary according to the cost and complexity of the device. For example, barrier devices are costly and difficult to fabricate and therefore designs for these devices are very detailed. Delineation devices, on the other hand, are not very expensive and can probably be fabricated easily. Therefore prototype designs for these devices are focused more on the shape and pattern of the devices to be tested.

A number of the devices already have prototypes built by the original proposers. These devices were placed in a "fast track" category that can be quickly tested and implementation in project H-109.

The automatic guided warning vehicle (AGWV) was found to be feasible with some changes to the original proposal. The complete feasibility study of the AGWV is given in Appendix K.

Table 3

Final Status of Device Designs

Area 1-Barrier Design	Status
855 - Tote Trailer for Sand Barrels	Design complete
317 - S.CAI Barrier	Proposer has prototype
SI1 - Personnel Protection Trailer	Design complete
SI2 - Movable Barrier End Treatment	Design complete
SI3 - Reusable TMA	Concept Altered to Aluminum Can TMA
SI4 - Snow Plow TMA Interface	Design complete
Area 2 - Warning Device Prototypes	
506 - Work Area Intrusion Alarm	Infrared prototype
810/807 - Personnel Early Warning System	Used for alarm unit
843 - Life Saver	Ultrasonic prototype
739 - The Lookout	Pressurized hose-design complete
108 - Early Warning Device	Combined with 739
692 - Infrared Errant Vehicle Detector	Combined with 506
912 - Infrared Queue Length Detector	Design Complete
670 - Portable Protective Warning System	Abandoned
270 - Buffer Zone Alert System	Combined with 739
Area 3 - Rumble Strip Fabrication and Testing	
118 - Work Zone Rumble Strips	Design complete
933 - Portable Traffic Warning Speed Bumps	Design complete
187 - Portable Rumble Mat	Design complete
287 - Safe Speed Reduction Mat	Combined with 187
Area 4 - Delineation Device Fabrication and Testing	
310 - Opposing Traffic Lane Dividers	Design complete
002 - Direction Indicator Barricade	Design complete
990 - Fiber Optic Caltrop	Abandoned
579 - Retractable Transition Device	Abandoned
941 - Portable Soft Barricade System	Design complete
156 - Delineator Hose	Combined with 118
SI6 - Moving Taper	Design complete

Table 3 (concl.)

Area 5 - Lighting Device Testing

068 - The Guiding Light	Design complete
172 - Snow Plow Blade Markers	Design complete
049 - Attentive Signing Device	Abandoned
918 - Police Light Assembly	Abandoned
319 - TROTAR	Abandoned
SI7 - Diverging Light	Design complete

Area 6 - Sign Fabrication and Testing - Human factors complete

032 - Portable Sign Stand and sign	Proposer has prototype
999 - Flow through Stop and Slow Paddle	Abandoned
161 - Flashing Stop/Slow Paddle	Proposer has prototype
SI5 - Flagger Gate	Design complete
467 - Truck Mounted Message Box	Design complete
875 - Alternate Merge Signs	Abandoned

Area 7 - High Potential-High Risk Concept Development

890 - Automatic Mobile Warning Vehicles	Feasibility study complete

Summary

24 Devices designed

8 Devices abandoned

1 Device proven feasible

4

Conclusions and Recommendations

The major conclusion of this study is that there is a need for better devices, materials and methods for conducting highway maintenance work. Many of the existing traffic control devices and protection devices are only useable in long-term work zones that have a duration of at least three days. Other projects in the Strategic Highway Research Program are directed at improved materials and methods for pavement repair and rehabilitation. The primary focus of this project was on new devices to be used for traffic control and worker protection in maintenance work zones.

Most maintenance work zones are short-term (12 hours or less duration) and many of them involve mobile or moving operations. Therefore, devices must be mobile and dynamic to accurately reflect the quickly changing location and condition of the work zone.

The accidents and operational studies revealed a problem with the credibility of maintenance work zone signs and other traffic control devices. These studies also revealed that some drivers did not respond to even credible and standard traffic control devices that were warning them of the presence of maintenance work. This conclusion points to the need for worker warning and protection devices as well as improved traffic control devices.

The devices developed in this project should save lives of maintenance workers and motorists traveling in maintenance work zones. The devices should be tested as required to ensure their adoption by the highway maintenance community. Implementation packages should be developed through tests with active maintenance crews in open highway conditions.

More specific conclusions that relate to maintenance work zone safety that were not addressed in devices designed include:

1. Shadow vehicles are the most often struck in the rear-end. The drivers of these vehicles should be protected with high back seats and lap and shoulder seat belts.

2. Cab shields on dump beds were observed to crush the roof of truck cabs in overturning collisions. These shields should be removed and made to only cover the cab during loading operations. Trucks such as shadow vehicles should be equipped with roll cages to protect drivers when the truck overturns.

5

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Appendix A

Accident Data Analysis

Maintenance Safety Problems

To collect and analyze information on the safety problems experienced in short-term, mobile and moving maintenance operations, six State highway departments and one toll highway authority were asked and agreed to furnish accident information. In meetings with safety personnel in each agency at least five years of accident data on worker accidents was requested. Most agencies had files on accidents involving maintenance vehicles which were also requested. In some agencies other specific sets of data (such as snow plow accidents) were available and were requested. The agencies that furnished accident data and the type of data received are shown in Table A-1.

A coding form was developed in order to get the accident data into a consistent format and to allow analysis of areas important to the contract. The form is shown in Figure A-1. The twenty-four fields on the form describe the maintenance activity and the type of work zone (stationary, mobile, moving) where the accident occurred. The last three fields contain the description of the accident (state's narrative) and information that the project staff may want to enter, (such as "good example of problem in flagging operations"). Not shown in Figure A-1 is the 24th field on driver condition.

Table A-1

States Furnishing Accident Data

State or Agency	Data Received	Number of Reports Coded
Florida	Worker Injury and Vehicle Accident Summaries	78
Iowa	General Accident Summaries and Worker Injury Data (82-86)	58
Missouri	Worker Injury Data (87-88)	40
Nebraska	Worker Injury Data (82-97)	43
New York Thruway	Maintenance Department Reports (87-88)	55
Virginia	Work zone Accident Summaries (85-87)	25
Washington	Worker Injury Data (82-86)	25
		324

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ACCIDENT CODER ____________________ DATA ENTRY ______________________________

REC NUM	STATE_CODE 1	DATE 2	TIME 3	OPERATION 4	AREA 5	LOCATION 6	TYPE_WORK 7	ROAD_TYPE 8	ST_MI_FI 9	ROAD_COND 10	WEATHER 11	MANNER_1 12	MANNER_2 13	ACC_TYPE 14	SEC_EVENT1 15	SEC_EVENT2 16	VEH1_TYPE 17	VEH2_TYPE 18	SEVERITY 19	NO_FATALS 20	NO_INJURYS 21	DESCRIPTIO 22	OTHER 23
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Figure A-1 - Accident Coding Form

As shown in Table A-1 useable accident data was received and coded for the States of Florida (84-87), Iowa (82-86), Missouri (87-88), Nebraska (82-87), Washington (82-86), and Virginia (85-87). Data was also received from the New York State Thruway Authority (87-88), The form of the accident data varied from hard copy police accident reports, to maintenance department reports to short summaries prepared by the personnel safety department. One other State furnished reports from the State's work zone accident data base. However, no maintenance accidents were found in this data base.

The coded data was entered into GME computers utilizing DBase III plus Software. The accident data base contains 324 maintenance work zone accidents including 17 fatal, 208 injury, and 99 property damage only (PDO) accidents. Although the accidents came from different regions of the country, the data are probably not statistically representative of all maintenance work zone, because there are more northern (snow belt) States in the sample, which shows up in the data frequency of snow removal related accidents. Fatal and injury accidents are probably over-represented since these types of accidents were requested. However, since statistics on 15 types of maintenance operations are presented, the data give a good picture of typical maintenance safety problems.

Table A-2 shows the breakdown of the number and severity of accidents that occurred for each maintenance operation. The operation with the largest number

Table A-2

Maintenance Operation Accidents by Severity

Operation	Fatality	Injury	PDO	Total	Percent F + I
Snow and Ice Control	1	32	34	67	49.3
Pavement Maintenance	5	29	10	44	77.3
Flagging	1	19		20	100.0
Sweeping	1	8	10	19	47.4
Pavement Marking		12	6	18	66.7
Bridge Maintenance	3	11	2	16	87.5
Roadside Maintenance		7	6	13	53.8
Transport Equip & Matl		9	3	12	75.0
Mowing	1	7	2	10	80.0
Emergencies		6	3	9	66.7
Surveying		9		9	100.0
Traffic Services		4	1	5	80.0
Weed Control		3		3	100.0
Drainage		2	1	3	66.7
Shoulder Maintenance		2		2	100.0
Miscellaneous & Unknown	5	48	21	74	71.6
Total	17	208	99	324	69.4
Percent	5.2	64.2	30.6	100.0	

Iowa Florida Nebraska Missouri New York Washington Virginia

PDO - Property Damage Only Accidents

Percent F + I - Percentage of fatal plus injury accidents

of accidents is snow and ice control with 67 of the 324 accidents. The operations with the largest totals are:

1. snow and ice control (67)
2. pavement maintenance (44)
3. flagging(20)
4. sweeping (19)
5. pavement marking (18)

Examination of the more severe accidents shows that pavement maintenance experienced the most fatal accidents followed by bridge maintenance. For the total of fatal and injury accidents pavement maintenance had 34 fatal or injury accidents followed by snow and ice control (33), flagging (20), bridge maintenance (14) and pavement marking operations (12).

The accident data did not always specify the type of maintenance operation and therefore there are a large number of accidents where the type of maintenance operation could not be determined. Other categories of data also contain large numbers of unknowns based on the format of the available data. Some states were recontacted to obtain additional information to reduce the number of unknowns in the data base, but in many cases information about the maintenance operation was not recorded.

Table A-3 - Type of Work by Severity reinforces the results shown in Table A-2. Moving operations had the largest number of accidents. However, more than half of the fatal accidents were during the short-term stationary operations. Mobile and short-term stationary operations where pedestrian workers are usually present have a much higher proportion of fatal and injury accidents.

Table A-3 - Type of Work by Severity

Type of Work	Severity of Maintenance Accidents				
	Fatality	Injury	PDO	Total	Percent F + I
Moving	2	65	57	124	54.0
Short-term Stationary	9	64	17	90	81.1
Mobile	3	39	8	50	84.0
Unknown	3	40	17	60	71.7
Total	17	208	99	324	69.4
Percent	5.2	64.2	30.6	100.0	

Iowa Florida Nebraska Missouri New York Washington Virginia

PDO - Property Damage Only Accidents

Percent F + I - Percentage of fatal plus injury accidents

Table A-4 shows a summary of the road type where the accidents occurred. Almost half the accidents occurred on freeways. Also 12 of the 17 fatal accidents occurred on freeways. The percentage of fatal and injury accidents was highest for two-lane highways (83.1%).

Table A-5 presents the types of maintenance accidents by severity. Almost all of these accidents (95%) involved work vehicles and workers. Almost two-thirds of the accidents involved collisions with work vehicles. Five of the seventeen fatal accidents are of this type. Except for run-off-the-road accidents, work vehicle accidents are least severe in terms of percentage of fatal plus injury accidents. These accidents reinforce the need for work vehicles to be used as protective vehicles near workers. It also shows the safety advantages of keeping workers in vehicles while on the roadway.

The next most frequent accident types in Table A-5 involve workers and include, vehicles striking pedestrian workers, foreign object damage from objects being blown by the wind, thrown, or falling off of vehicles, and accidents where pedestrian workers were injured while avoiding errant vehicles. These accidents are the most severe. Eleven of the seventeen fatal accidents involved pedestrian workers. These accidents point to the need for protecting workers or alerting them of danger when an errant vehicle enters the transition area, buffer space, or work space; the areas of the work zone set aside for workers, vehicles and equipment.

Table A-4 - Road Type by Severity

Road Type	Severity of Maintenance Accidents				
	Fatality	Injury	PDO	Total	Percent F + I
Freeway	12	86	60	158	62.0
Two-lane	2	47	10	59	83.1
Multi-lane Divided	1	20	16	37	56.8
Multi-lane Undivided		4	2	6	66.7
Unknown	2	51	11	64	82.8
Total	17	208	99	324	69.4
Percent	5.2	64.2	30.6	100.0	

Iowa Florida Nebraska Missouri New York Washington Virginia

PDO - Property Damage Only Accidents

Percent F + I - Percentage of fatal plus injury accidents

Table A-5 - Accident Type by Severity

Accident Type	Fatality	Injury	PDO	Total	Percent F + I
	Severity of Maintenance Accidents				
Work Vehicle	5	112	92	209	56.0
Pedestrian Worker	10	58	1	69	98.6
Foreign Object Damage (FOD)		17	1	18	94.4
Pedestrian Worker Avoiding Vehicle	1	11		12	100.0
Work Zone Traffic Control Device	1	2	1	4	75.0
Ran Off Roadway Only		2	2	4	50.0
Other Motor Vehicle		2	1	3	66.7
Submersion		1		1	100.0
Overturned		1		1	100.0
Median/Barrier		1		1	100.0
Windshear			1	1	0.0
Other		1		1	100.0
Total	17	208	99	324	69.4
Percent	5.2	64.2	30.6	100.0	

Iowa Florida Nebraska Missouri New York Washington Virginia

PDO - Property Damage Only Accidents

Percent F + I - Percentage of fatal plus injury accidents

Table A-6 presents manner of collision by severity. Rear-end accidents are the most frequent manner of collision. There were six fatal rear-end accidents and these primarily involved work vehicles (Table A-5), but the relative severity of these accidents was about the same as for all maintenance accidents. Thirty-six of rear-end involved snow plows, including one fatal and 23 injury accidents. Snow plow accidents had the same relative severity as other rear-end accidents.

Single vehicle accidents were the next most frequent manner of collision in Table A-6 included ten fatal accidents involving pedestrian workers. Except for manners of collision with few accidents, single vehicle accidents were the most severe.

Overtaking accidents occur when one vehicle is passing another in the same direction. These are the next most frequent manner of collision in Table A-6 and are the least severe manner of collision. Of these, 11 involved snow plows which had the same relative severity as other overtaking accidents. Rear-end (36 accidents) and overtaking (11) comprise 85 percent of the snow plow accidents.

The relative severity of accidents was calculated by summing the fatal and injury accidents and dividing by the total number of accidents. The severity of all accidents shows that 69.4 percent of the accidents resulted in an fatality or injury. Accident sets with a higher percentage are more severe than the "typical" overall accident set and those with a lower percentage less severe.

Table A-6 - Manner of Collision by Severity

Manner of Collision	Severity of Maintenance Accidents				Percent
	Fatality	Injury	PDO	Total	F + I
Rear End	6	86	46	138	66.7
Single Vehicle	10	94	5	109	95.4
Overtaking	1	6	27	34	20.6
Right Angle		5	3	8	62.5
Left Turn		3	2	5	60.0
Head On		1	3	4	25.0
Right Turn			2	2	0.0
Side Swipe		1		1	100.0
Other		5	7	12	41.7
None		1	1	2	50.0
Unknown		6	3	9	66.7
Total	17	208	99	324	69.4
Percent	5.2	64.2	30.6	100.0	

Iowa Florida Nebraska Missouri New York Washington Virginia

PDO - Property Damage Only Accidents

Percent F + I - Percentage of fatal plus injury accidents

The statistics show that for flagging, shoulder maintenance, surveying, and weed control operations, all accidents resulted in a fatality or injury. Other accident sets that are more severe than the "typical" accident set include, bridge maintenance, mowing, pavement maintenance, sweeping, and transporting equipment and materials.

The two operations that are least severe are sweeping and snow and ice control. Both of these operations utilize large work vehicles that protect their drivers or workers.

These results show a pattern that is clear throughout the accident data: moving operations experience the most accidents, but operations such as pavement maintenance, flagging and bridge maintenance have a larger proportion of severe accidents.

Typically accident rates are computed based on the number of accidents per 100 million or per million vehicle miles of exposure. This exposure measure is obtained by multiplying duration x mileage x ADT.

Because of the short and varying duration of maintenance activities and due to the length of roadway covered in moving activities, it is not possible to compute accident rates based on vehicle miles of exposure.

Most states do record the number of personnel hours spent in various maintenance activities. These data were added and averaged for five different agencies in hope of getting a measure of the exposure of various activities. The agencies and the number of years of data are New York DOT (1987), Iowa DOT (1983-87), California DOT (1984-87), New York Thruway Authority (1984-87) and Florida DOT (1984-87).

The Maintenance accidents and the sum of the hours in various activities are shown in Table A-7. Although the analysis is somewhat hampered by differences in categories of operation, this table does contain some interesting comparisons of the time spent versus accident experience. For example, snow and ice control averages about 15% of the hours spent in the five agencies. However, snow and ice control accidents represent about 21% of the maintenance work zone accidents. Therefore, it would appear that snow and ice control operations are more hazardous than other types of maintenance operations.

In contrast, operations involving drainage operations only represent 1% of the accidents but average 8.4% of the hours spent in the five agencies. This result would indicate that there are fewer accidents for each hour spent in drainage operations than for other operations such as snow and ice control.

The data in Table A-7 was further categorized by on roadway stationary operations, such as pavement maintenance, on roadway moving operations such as pavement marking, and off roadway activities such as mowing. Totals for each category reveal that on roadway stationary operations represent 32.4% of the maintenance accidents and about 29% of the maintenance hours are spent in these

Table A-7

Maintenance Accidents and Hours Spent on Maintenance Activity

Operation	Severity Fatality	%	Injury	%	PDO	%	Total	%	Average Hours %	Sum of Hours
ON ROADWAY STATIONARY	9	52.9	80	38.5	16	16.2	105	32.4	29.0	7,637,190
Bridge Maintenance	3	17.6	11	5.3	2	2.0	16	4.9	4.5	1,189,675
Pavement Mainteance	5	29.4	29	13.9	10	10.1	44	13.6	12.2	3,215,051
Shoulder Maintenance			2	1.0		0.0	2	0.6	5.9	917,746
Emergencies			6	2.9	3	3.0	9	2.8	2.0	477,199
Surveying			9	4.3		0.0	9	2.8		
Flagging	1	5.9	19	9.1		0.0	20	6.2		
Traffic Services			4	1.9	1	1.0	5	1.5	7.0	1,837,520
ON ROADWAY MOVING	2	11.8	61	29.3	53	53.5	116	35.8	14.7	3,868,287
Pavement Marking			12	5.8	6	6.1	18	5.6	2.4	326,894
Snow and Ice Control	1	5.9	32	15.4	34	34.3	67	20.7	14.9	3,472,112
Sweeping	1	5.9	8	3.8	10	10.1	19	5.9	2.2	69,281
Transport Equip & Matl			9	4.3	3	3.0	12	3.7		
OFF ROADWAY	1	5.9	19	9.1	9	9.1	29	9.0	28.6	7,549,332
Roadside Maintenance			7	3.4	6	6.1	13	4.0	18.5	4,879,687
Mowing	1	5.9	7	3.4	2	2.0	10	3.1	7.2	307,328
Weed Control			3	1.4		0.0	3	0.9	3.5	150,549
Drainage			2	1.0	1	1.0	3	0.9	8.4	2,211,768
Miscellaneous & Unknown	5	2.9	48	23.1	21	21.2	74	22.8		
Administrative									12.8	3,384,541
Rest Areas and Parks									2.3	548,860
Extra Service Contracts									0.4	8,016
General Maintenance									10.7	195,077
Work for Others									1.2	22,178
Maintenance of Special Highways									0.9	83,566
Equipment Maintenance									10.8	1,030,046
Residency Operations									12.8	1,217,984
Other Structures									3.2	340,974
Electrical									4.4	467,501
Total	17	100.0	208	100.0	99	100.0	324	100.0		26,353,553

activities. On roadway moving activities represent 35.8% of the accidents but only 14.7% of the maintenance hours. Off roadway activities represent 9.0% of the maintenance accidents, but 28.6% of the maintenance hours spent.

The results of this accident versus hours analysis indicate that on-road moving activities are the most hazardous followed by on-road stationary activities. Off-road activities are much less hazardous than on-road activities.

These results are supported by the analysis of location of the work (in the traveled way, on the shoulder, or on the roadside) shown in Table A-8. Over two-thirds of the accidents occurred in the traveled way, indicating that there is the greatest risk involved in work that is on the traveled way.
Other categories were analyzed according to the severity of accidents and yield the following results:

1. There were 125 cars, 66 semi-trucks, and 32 pickups involved in the accidents.

2. More accidents occurred in rural areas and the accidents were also more severe in rural areas. (Ten of 17 fatal accidents occurred in rural areas).

3. Only 12 of the 324 accidents occurred at the start or near the finish of the work when traffic controls were being installed or removed.

4. The most common road and weather conditions were clear and dry followed by snow covered and snowing

5. The most common type of maintenance vehicles involved were traffic control (protection) vehicles followed by snow plows and dump trucks.

Table A-8 - Location by Severity

Location	Severity of Maintenance Accidents				
	Fatality	Injury	PDO	Total	Percent F + I
Traveled Way	11	130	81	222	63.5
Shoulder	2	24	12	38	68.4
Roadside		4	1	5	80.0
Unknown & Other	4	50	5	59	91.5
Total	17	208	99	324	69.4
Percent	5.2	64.2	30.6	100.0	

Iowa Florida Nebraska Missouri New York Washington Virginia

PDO - Property Damage Only Accidents

Percent F + I - Percentage of fatal plus injury accidents

6. Driver condition in these accidents were mainly unknown. At least 19 of the 324 accidents did involve drinking or drug use by the motorist (not highway worker) involved.

7. Two-thirds of the accidents occurred between 9 am and 4 pm. The most frequent hours were between 10 am and 11 am when 47 accidents occurred.

The most dramatic fatal accidents were analyzed and reconstructed to get more insight into the circumstances of severe maintenance accidents. Given below are descriptions of five of these accidents.

1. In an Interstate highway patching operation, a large bus went through a taper of cones, hit an arrow panel trailer, pushed the trailer into the rear of a shadow vehicle, went through a work crew striking three workers, crossed through a large hole where concrete had been removed, struck another maintenance truck and pushed it into a third maintenance truck before coming to a stop. Testimony and reconstruction have the bus traveling in excess of 61 mph prior to impact with the first maintenance truck. This would mean that there was over 6.5 seconds between the time the bus hit the first cone and the time it hit the first maintenance vehicle. At no time did the bus driver brake during this crash sequence. The bus driver was decapitated, probably during the collision with

the arrow panel trailer. Investigators suspect the bus driver suffered a heart attack prior to the accident, making him unable to control the bus. The driver and one maintenance worker were killed: two other maintenance workers were seriously injured.

2. A Dodge K - car travelling on a Interstate highway hit the back of a dump truck being used as a shadow vehicle for a mowing operation. The car spun out and was subsequently hit by a semi-tractor-trailer, which tore it in half. The impact with the semi-tractor-trailer also forced the K-car into the mower. The driver of the K-car was killed. The driver of the shadow vehicle, mower, and semi-tractor-trailer were all seriously injured.

3. A worker was standing on a rest area exit, six feet from the edge of the driving lane, marking joints for repair. A pickup camper veered off the driving lane for no apparent reason and hit the worker, killing her.

4. A worker was repairing a sprinkler riser on the off ramp of an Interstate highway. An exiting vehicle went out of control for no apparent reason and struck the worker, killing her.

5. A worker was stopped on the right shoulder of a roadway to tighten the lug nuts on the left rear wheel of his sweeper. An errant semi-tractor-trailer loaded with lumber hit the shadow vehicle behind the sweeper, which in turn hit the worker fixing the sweeper, killing him.

The fatal accident review shows that workers need to be protected from errant vehicles and warned when an errant vehicle enters the transition, buffer space, or work space. Some of these accidents happened for no apparent reason.

Appendix B

Operational Studies

Typical maintenance activities were studied by videotaping actual maintenance operations in eight States. A total of 91 studies were completed ranging in length from as short as five minutes to as long as four hours. More than 96 hours of maintenance activity were videotaped. Speeds of vehicles approaching and near maintenance work areas were recorded using dual mode (stationary and moving) radar.

Figure B-1 shows the number of studies completed in each area type, road type, location, and type of work. Numbers in parenthesis are the number of studies proposed in each category. The greatest variance in the studies over those planned was in multi-lane undivided highways in rural areas. Since there are few multi-lane highways in rural areas, it was difficult to videotape actual maintenance operations for these categories. In contrast, operations on freeways were studied at more sites than originally planned.

A wide variety of maintenance operations were studied as shown in Table B-1. The type of operation most studied was asphalt pavement repair with eleven studies. Snow removal, painting and striping, and utility work were each videotaped at six sites.

	Urban			Rural			
	F	M	T	F	M	T	Total
On Travel Way							
Moving	5(4)**	2(4)	1(2)	4(2)	2(2)	2(2)	16(16)
Mobile*	5(4)	3(4)	1(2)	2(2)	0(2)	2(2)	13(16)
Short-term Stationary*	7(8)	3(8)	6(2)	4(4)	1(4)	4(4)	25(30)
Subtotal	17(16)	8(16)	8(6)	10(8)	3(8)	8(8)	54(62)
Off of Travel Way							
Moving	4(2)	0(2)	0(1)	2(1)	0(1)	4(1)	10(8)
Mobile*	5(2)	1(2)	1(1)	5(1)	0(1)	1(1)	13(8)
Short-term Stationary*	2(2)	5(4)	0(1)	4(2)	0(2)	3(2)	14(15)
Subtotal	11(8)	6(8)	1(3)	11(4)	0(4)	8(4)	37(31)
Total	27(24)	13(24)	9(9)	19(12)	4(12)	17(12)	91(93)

F - Freeways and divided facilities
M - Multi-lane undivided facilities
T - Two-lane facilities

* - Time-task studies of flagging operations were also conducted during these maintenance operations

** - ( ) - number of studies proposed

Figure B-1 - Maintenance Work Zone Video Tape Studies Completed

Table B-1

Maintenance Operations Videotaped

1. Asphalt Pavement Repair (11)*
2. Attenuator Repair (1)
3. Bridge Maintenance (2)
4. Brush Clearing (2)
5. Crack Sealing (4)
6. Curb and Sidewalk Repair (1)
7. Ditch Cleaning (4)
8. Excavating (1)
9. Flagging (2) (Flagging was also observed in 12 other studies)
10. Guardrail repair (4)
11. Herbicide Spraying (3)
12. Joint Repair (2)
13. Mowing (2)
14. Luminairre Repair (1)
15. Mud Jacking (1)
16. Pothole Patching (4)
17. Roto Milling (3)
18. Salting and Sanding (1)
19. Sand Blasting (1)
20. Shoulder Maintenance (4)
21. Sign Repair (5)
22. Snow Blowing (3)
23. Snow Removal (6)
24. Surveying (2)
25. Sweeping (2)
26. Painting and Striping (6)
27. Traffic Signal Adjustment (3)
28. Trash Pickup (1)
29. Utility Work (6)
30. Barrier Installation (3)

* Numbers in parenthesis represent the number of studies completed

The videotapes normally contain a drive-thru to display the traffic controls visible to drivers passing the work area. Where possible the deployment and pickup of traffic control devices were also videotaped. Two Quasar S-VHS camcorders were used to videotape the maintenance activities. Many of the studies utilized only one camera with a view of both traffic approaching the work area and worker's actions in the work area. Some of the studies involved both cameras running simultaneously.

The tapes were played back on a S-VHS VCR and 22 inch color monitor for analysis. There were five basic steps in the analysis effort.

1 - establish a directory of the tape telling the clock and video times associated with start, finish, and other significant events (such as severe conflicts);

2 - count cars and trucks for each direction of traffic affected by the maintenance activity;

3 - record speeds taken during the studies and recorded on the audio portion of the videotape;

4 - observe, classify and count conflicts observed;

5 - determine typical time-task plots for each maintenance operation.

Serious conflicts or near accidents were observed in 22 of the studies. In these studies, 29 separate incidents were observed. These incidents are described in Table B-2. Seven of the serious incidents involved flaggers. Either vehicles violated the STOP/SLOW signal of the flagger or the flagger had to resort to unusual methods to get a vehicle to stop. Six of the incidents involved vehicles

Table B-2 - Video Studies

Serious Conflicts and Near Accident Observed

Study	Maintenance Operation	Area	Work Location	Road Type	Description of Incident	Contributing Circumstance
1	Shoulder Maintenance	Rural	Off TW	Two-lane	A truck did not stop for flagger.	Flagging operation temporary at job site.
2	Excavating	Rural	Off TW	Two-lane	A. The flagger released a queue of cars when there was a car coming from the other direction.	Car pulled out from a side street between flaggers.
					B. A truck drove past the flagger's stop sign.	Driver did not obey stop signs.
3	Pothole Patching	Urban	On TW	Freeway	Vehicle got stuck in behind arrow panel truck.	Vehicle wanted to exit right, but maintenance crew had exit blocked temporarily.
4	Guardrail Repair	Urban	On TW	Freeway	A. A car drove inside cones then back into traffic.	Traffic was moving slowly thru work zone. The car had to swerve into the work area to avoid hitting slowing car in front.
					B. A pickup slammed on it's brakes and slid sideways.	Arrow panel truck on shoulder picking up signs w/arrow panel in arrow mode, causing traffic to merge right.

Table B-2 - Video Studies (cont.)

Serious Conflicts and Near Accident Observed

Study	Maintenance Operation	Area	Work Location	Road Type	Description of Incident	Contributing Circumstance
5	Pothole Patching	Urban	On TW	Freeway	A. A car came up an on-ramp and entered caravan between work vehicle and protection vehicle. When vehicle merged into open lane it was almost side-swiped.	Maintenance crew working on-ramp area, arrow panel truck at the on-ramp did not stop ramp traffic.
					B. A car slowed behind the attenuator truck causing traffic jam, some vehicles pass on the shoulder.	Indecision about where to exit. Arrow panel hard to observe due to vertical curve.
6	Attenuator Repair	Urban	Off TW	Freeway	A. Car got confused because of cones in gore are and had trouble making lane change.	Car waited too long to make a safe lane change.
					B. Two vehicles drove thru gore area.	Car in exit lane turned into main line of traffic thru gore area.

Table B-2 - Video Studies (cont.)

Serious Conflicts and Near Accident Observed

Study	Maintenance Operation	Area	Work Location	Road Type	Description of Incident	Contributing Circumstance
7	Pothole Patching	Urban	On TW	Freeway	Cars slow behind operation, one car skidded and ran off shoulder.	Arrow panel truck in center lane, semi-truck stops behind arrow panel truck blocking view of arrow panel.
8	Crack Sealing	Urban	On TW	Freeway	A truck came up on an on-ramp passed caravan on the right side, when advance warning vehicle was directing left.	Driver of truck did not observe the arrow panel signal.
9	Utility Work	Urban	Off TW	Freeway	Utility truck pulled out in front of car, and crossed lane causing car to brake.	Truck driver did not look to see if traffic was clear.
10	Snow Removal	Urban	On TW	Freeway	A truck entering traffic lane slid sideways because of road condition.	Blowing snow and hard packed snow on road.

Table B-2 - Video Studies (cont.)

Serious Conflicts and Near Accident Observed

Study	Maintenance Operation	Area	Work Location	Road Type	Description of Incident	Contributing Circumstance
11	Crack Sealing	Urban	On TW	Two Lane	A. While flagger had his back to traffic, 2 cars at different times make right turns when they should be stopped.	The flagger was moving from one location to his next location. He was moving in the same direction as operation. When he stopped the the street entrance was between flaggers.
					B. Flagger stepped in front of car to prevent car passing flagger on shoulder.	Intersections in one-way section of work zone.
12	Painting Stripping	Rural	On TW	Two Lane	Two vehicles passed arrow-panel truck on the left side. Arrow panel was pointing right.	One truck and one car did not want to drive on the right side (shoulder).

Table B-2 - Video Studies (cont.)

Serious Conflicts and Near Accident Observed

Study	Maintenance Operation	Area	Work Location	Road Type	Description of Incident	Contributing Circumstance
13	Asphalt Overlay	Urban	On TW	M-L Undivided	A. Car drove past policeman into work area.	Car did not observe policeman's signals. Policeman did stop car in time.
					B. A car pulled into open lane from side street and stopped near work area.	Driver looking at work operation.
14	Asphalt Overlay	Urban	On TW	M-L Undivided	A truck turned across fresh asphalt.	The truck wanted to turn into a driveway
15	Crack Sealing	Rural	On TW	Freeway	A car swerved behind advanced warning truck, then back into lane.	Curve obscured work location traffic caused vehicle to slow before merging.
16	Utility Work	Urban	On TW	M-L Undivided	Work truck blocked traffic causing car to go down wrong side of street.	Driver impatient made left turn thru work zone. Utility work in middle of street.

Table B-2 - Video Studies (cont.)

Serious Conflicts and Near Accident Observed

Study	Maintenance Operation	Area	Work Location	Road Type	Description of Incident	Contributing Circumstance
17	Utility Work	Urban	On TW	M-L Undivided	Car pulled out from parking lot and crossed the on-coming traffic causing on-coming car to swerve.	Work vehicle blocked view of on-coming traffic.
18	Snow Removal	Rural	On TW	Freeway	A car was trapped be-behind snow plow.	Car behind snow plow, wanted to change lanes, but not sure of snowy road conditions.
19	Asphalt Repair	Urban	On TW	Freeway	A. Cars slowed down causing traffic jam.	Three lanes of traffic merging to one lane in work zone.
					B. Cars exit through cones closing exit ramp.	Three lanes of traffic merging to one lane, not enough advance warning.
20	Roto Milling	Urban	On TW	Freeway	Left turning vehicles in dual left turn lane were channelled into one lane near work area.	Two left turn lanes on approach had no warning signs about work zone

Table B-2 - Video Studies (concl.)

Serious Conflicts and Near Accident Observed

Study	Maintenance Operation	Area	Work Location	Road Type	Description of Incident	Contributing Circumstance
21	Roto Milling	Urban	On TW	Freeway	Near work area car swerved across gore.	Arrow panel was pointing left near gore area.
22	Shoulder Work	Rural	On TW	Freeway	A car tried to make a right turn into side road and turned through work area.	Flagger on other side of road talking to other workers, and not not observing traffic.

near on-ramps or off-ramps. In many cases on-ramp vehicles drove through or were trapped in a caravan of moving vehicles. Off-ramp vehicles often slowed when trying to decide weather to exit in front or behind the work vehicle caravan. Four incidents involved arrow panels. In some of these incidents the arrow signal was confusing to the motorist. In one incident the arrow panel was blocked by a truck that was trapped in the closed lane. Other incidents involved vehicles slowing to look at the work, vehicles that drove through work areas to turn into driveways, or poor advance warning near intersections.

In addition to serious incidents and near accidents, conflicts and erratic maneuvers that were recorded on the videotape were counted for each study. These counts and traffic volumes for each type of maintenance and operation are shown in Table B-3. The table shows the number of conflicts and erratic maneuvers for all of the studies of a particular type of maintenance operation. The operations are listed in the order of the highest conflict rates (conflicts per 100 vehicles).

Conflicts involve the interaction of two or more vehicles as evidenced by brake lights or swerving. There are several different types of conflicts such as slow vehicle, merging and stop in closed lane. The conflicts numbers were small and therefore the various categories were summed to give a total conflict number.

Table B-3

Summary

SHRP H-108 MAINTENANCE WORK ZONE SAFETY
GME PROJECT NO. C-10
TRAFFIC VOLUME AND CONFLICT SUMMARY

SORTED BY CONFLICT RATE PER 100 VEHICLES

OPERATIONS	DURATION (min.)	TRAFFIC VOLUME	VEH PER HOUR	TOTAL CONFLICTS	TOTAL CONFLICT RATE PER 100 VEH.	TOTAL CONFLICT RATE PER HOUR	TOTAL ERRATIC MANEUVERS	TOTAERRAT. ERRATIC MANEUVER RATE PER 100 VEH	MANEU. RATE PER HOUR
GUARDRAIL	295	5716	1163	125	2.2	25.4	38	0.7	7.7
SWEEPING	56	726	778	7	1.0	7.5	1	0.1	1.1
ATTENUATOR REPAIR	22	699	1906	3	0.4	8.2	4	0.6	10.9
ROTO MILLING	300	5634	1127	18	0.3	3.6	2	.0	0.4
POTHOLE PATCHING	69	2171	1888	6	0.3	5.2	12	0.6	10.4
UTILITY WORK	147	2405	982	6	0.2	2.4	34	1.4	13.9
PAVEMENT & ASPHALT REPAIR	726	10456	864	13	0.1	1.1	241	2.3	19.9
SHOULDER WORK	268	3248	727	0	0.0	0.0	3	0.1	0.7
STRIPING & PAINTING	330	3135	570	0	0.0	0.0	8	0.3	1.5
TRAFFIC SIGNAL ADJUSTMENT	126	2933	1397	0	0.0	0.0	4	0.1	1.9
FLAGGING	147	2418	987	0	0.0	0.0	2	0.1	0.8
SIGN REPAIR	274	2371	519	0	0.0	0.0	0	0.0	0.0
DITCH WORK	301	2369	472	0	0.0	0.0	0	0.0	0.0
CURB & SIDEWALK REPAIR	93	1320	852	0	0.0	0.0	0	0.0	0.0
JOINT REPAIR	150	1116	446	0	0.0	0.0	0	0.0	0.0
TRASH PICKUP	57	980	1032	0	0.0	0.0	0	0.0	0.0
EXCAVATING	121	943	468	0	0.0	0.0	1	0.1	0.5
CRACK SEALING	196	840	257	0	0.0	0.0	5	0.6	1.5
BARRIER INSTALLATION	39	694	1068	0	0.0	0.0	0	0.0	0.0
CLEANING UP BRUSH AND TREES	60	507	507	0	0.0	0.0	0	0.0	0.0
SNOW REMOVAL	125	463	223	0	0.0	0.0	3	0.6	1.4
SURVEYING	56	386	414	0	0.0	0.0	0	0.0	0.0
HERBICIDE SPRAYING	101	341	203	0	0.0	0.0	1	0.3	0.6
MOWING	50	286	343	0	0.0	0.0	0	0.0	0.0
SNOW BLOWING	109	282	155	0	0.0	0.0	0	0.0	0.0
LUMINAIRE REPAIR	34	258	455	0	0.0	0.0	0	0.0	0.0
MUD JACKING	139	222	96	0	0.0	0.0	0	0.0	0.0
BRIDGE MAINTENANCE	36	69	115	0	0.0	0.0	0	0.0	0.0
SANDBLASTING	3	56	1344	0	0.0	0.0	0	0.0	0.0
SALTING & SANDING	18	25	83	0	0.0	0.0	0	0.0	0.0
TOTAL	4447	53069	716	178	0.3	2.4	359	0.7	4.8

Conflicts were only noted for seven types of maintenance operations. These operations in rank of conflict rate were:

1. Guardrail repair;

2. Sweeping;

3. Attenuator repair;

4. Tie, Pothole patching and roto milling

6. Utility work; and

7. Pavement and asphalt repair

Many of these operations were also ranked high in the number of maintenance work zone accidents discussed in Appendix A. Conflicts are also related to the traffic volume per hour, most of the top seven operations in Table B-3 have high traffic volumes. No conflicts were noted for the other types of maintenance operations.

Erratic maneuvers are sudden swerving or braking actions by individual vehicles. Erratic maneuvers were counted at the same time as conflicts by observing the videotapes. The total erratic maneuver rate per 100 vehicles is also shown in Table B-3. The top seven operations by the erratic maneuver rate are:

1. Pavement and asphalt repair;
2. Utility work;
3. Guardrail repair;
4. Tie, Attenuator repair, pothole patching, crack sealing, and snow removal.

The videotapes were useful in giving the project staff and others a view of the way maintenance activities are actually conducted. For example, it is clear from the videotapes that flaggers have their backs to traffic a great deal of the time in order to communicate with other flaggers and to watch opposing traffic queues. Many flaggers stand sideways in order to look up and down the roadway. When they are standing sideways their vests are very hard to see.

Several edited VHS videotapes were made from the field tapes for use in presentations and for expert task group meetings. Tapes were made summarizing the following operations:

1. Snow removal
2. Two flaggers
3. Single flagger

4. Crack sealing

5. Pot hole patching

6. Variety of operations showing severe conflicts

Speeds were measured with an MPH 55 Radar unit with settings for both stationary and moving radar measurements. This unit also had two antennas which were normally aimed out the front and rear of the data collection vehicle.

The normal speed study procedure was to park the data collection vehicle about 200 to 300 feet from the work area. As a vehicle approached the work area, it's speed was measured using the rear-aimed antenna of the radar unit. Speeds vehicle identification, and location data were recorded on the videotapes being recorded at the same time.

After the vehicle passed the van and when it was near the work area, it's speed was again recorded using the front-aimed antenna.

For moving and mobile operations the data collection vehicle moved slowly with the operation but speeds were recorded in the same manner using the stationary setting of the radar unit. (Only opposing direction vehicles could be measured with the moving radar).

Speed measurements were made during 37 of the operational studies. Ten of the studies were on two-lane highways, 5 on multi-lane undeveloped highways and 22 studies were on freeways. Normal speeds limits on the roadways varied from 35 to 65 mph.

Table B-4 presents an example of speed data and the speed distribution statistics for one maintenance work zone speed study. At each site there was a maximum of four sets of speed data: cars on the approach; cars near the work area; trucks on the approach; and trucks near the work area. For some sites it was not possible to obtain speeds in all four data sets. For each of the sets of speed data the standard statistics were computed including mean speed, sample variance, standard deviation, 85th percentile speed, median, mode, and 10 mph pace.

Summaries of the speed data are shown in Table B-5 - Two-Lane Speeds, Table B-6 - Multi-lane Undivided Speeds, and Table B-7 - Freeway Speeds. For each study the type of work, area type, speed limit, and mean speeds and 85th percentile speeds for the four sets of speed data mentioned above are shown.

In general speeds on the approach to the work zone were close to the speed limit. Car mean speeds were generally slightly higher than truck speeds. Some of the studies show that speeds in the work area were equal or higher than speeds on the approach. For example in Table B-6, study 1 shows that both cars and trucks speeded up from the approach to the work zone for a shoulder work site. Generally work in the traveled way had the most substantial speed reductions. For asphalt overlay jobs, speeds on the approach were up to 27 mph below the speed limit, speeds in the work area were not recorded for the asphalt overlay jobs.

Table B-4

SHRP H-108 SPOT SPEEDS

CARS

Observer: BM State: FLORDIA Study no.:01
Stationary: X Moving: Direction:NB
Time of Day:0940-1045 Duration:
Location: IN TRAVEL WAY APP WOR Speed lim: 45

Speed (mph) X	Observed Frequency f	%	Cummulative Frequency f	%	X*f	X*f*X X^2*f
26	2	3	2	3	52	1352
27	1	2	3	5	27	729
28	1	2	4	6	28	784
29	2	3	6	9	58	1682
31	4	6	10	16	124	3844
32	1	2	11	17	32	1024
33	2	3	13	20	66	2178
34	1	2	14	22	34	1156
35	4	6	18	28	140	4900
37	3	5	21	33	111	4107
38	1	2	22	34	38	1444
39	7	11	29	45	273	10647
40	4	6	33	52	160	6400
41	8	13	41	64	328	13448
42	4	6	45	70	168	7056
44	4	6	49	77	176	7744
46	3	5	52	81	138	6348
47	3	5	55	86	141	6627
48	3	5	58	91	144	6912
49	1	2	59	92	49	2401
50	1	2	60	94	50	2500
51	2	3	62	97	102	5202
56	2	3	64	100	112	6272
Total	64	100			2551	104757

Mean Speed Xbar	=	40	mph
Sample Variance S^2	=	49	mph^2
StDev S	=	7	mph
85th Percentile Speed	=	47	mph
Median Speed	=	46	mph
Mode	=	41	mph
10 mph Pace	=	35-44	mph

Cells without data were deleted to reduce the size of the table.

Table B-5 - Two-Lane Speeds

SS#	A	Type of Work	Road Type	Activity	Speed Limit	app. wk/ wk. area No. of Observations	c-app/wk area t-app/wk area Mean Speed	85%
1	R	St. Stat	2 L	Ditch Work	45	c 64/13	c 40/33	c 47/39
						t 8/	t 35/	t 39/
2	R	St. Stat	2 L	Excavating Shoulder	45	c /153	c /48	c /54
						t /30	t /46	t /52
3	R	St. Stat	2 L	Surveying	55	c 31/44	c 61/60	c 67/63
						t 6/7	t 59/59	t 60/62
4	R	Mov	2 L	Herbicide	55	c 10/6	c 56/34	c 64/41
						t 5/4	t 55/43	t 64/42
5	R	Mov	2 L	Aerating Shoulder	45	c 7/	c 45/	c 40/
						t 3/	t 33/	t 34/
6	R	Mov	2 L	Snow Removal Shoulder	55	c 3/	c 58/	c 66/
						t 4/	t /56	t /54
7	R	Mob	2 L	Working Turn Out	45	c /27	c /35	c /40
						t	t	t
8	R	Mob	2 L	Snow Blowing	55	c 4/4	c 56/59	c 59/
						t /2	t /51	t /45
9	R	Mob	2 L	Graveling on Shoulder	55	c 36/16	c 39/33	c 45/37
						t 13/10	t 37/36	t 45/45
10	U	Mob	2 L	Crack Sealing	35	c 16/37	c 27/28	c 29/30
						t	t	t

c - car
t - truck

app. wk. - approaching work zone
wk area - near work area
A - area - R (Rural)
U (Urban)
type of work - St. Stat (short-term stationary)
Mov (moving)
Mob (mobile)
road type - 2L (two-lane)
M (multi-lane undivided)
F (freeway)

Table B-6 - Multi-Lane Undivided Speeds

SS#	A	Type of Work	Road Type	Activity	Speed Limit	No. of Observations (app. wk/ wk. area)	Mean Speed (c-app/wk area, t-app/wk area)	85%
1	U	St. Stat	M	Putting dirt & gravel on shoulder.	45	c 41/32	c 41/42	c 44/46
						t 5/2	t 39/43	t 43/43
2	U	St. Stat	M	Installing fire hydrant	35	c 35/	c 38/	c 43/
						t 12/	t 37/	t 41/
3	R	Mob	M	Painting stop bars	55	c 8/	c 56/	c 59/
						t	t	t
4	U	Mov	M	Asphalt overlay	55	c /23	c /33	c /36
						t	t	t
5	R	Mov	M	Asphalt overlay	55	c 6/	c 33/	c 37/
						t 6/	t 34/	t 39/

c - car
t - truck

app. wk. - approaching work zone
wk area - near work area
A - area - R (Rural)
U (Urban)
type of work - St. Stat (short-term stationary)
Mov (moving)
Mob (mobile)
road type - 2L (two-lane)
M (multi-lane undivided)
F (freeway)

Table B-7 - Freeway Speeds

SS#	A	Type of Work	Road Type	Activity	Speed Limit	app. wk/ wk. area No. of Observations	c-app/wk area t-app/wk area Mean Speed	85%
1	R	St. Stat	F	Cleaning ditch w/ drageline	65	c /116 t /61	c /61 t /60	c /66 t /65
2	R	St. Stat	F	tree cutting	65	c /33 t /11	c /62 t /57	c /67 t /62
3	R	St. Stat	F	Underneath overpass expantion joint	65	c 6/7 t	c 63/45 t	c 67/48 t
4	R	St. Stat	F	Guardrail repair	55	c 23/30 t 3/11	c 56/58 t 58/54	c 62/62 t 62/57
5	U	St. Stat	F	Guardrail repair	55	c 37/28 t 17/9	c 52/44 t 48/42	c 58/51 t 54/46
6	U	St. Stat	F	Sandblasting under Bridge	55	c /70 t /17	c /56 t /53	c /59 t /57
7	U	St. Stat	F	Utility	55	c 15/ t	c 51/ t	c 56/ t

c - car
t - truck

app. wk. - approaching work zone
wk area - near work area
A - area - R (Rural)
U (Urban)
type of work - St. Stat (short-term stationary)
Mov (moving)
Mob (mobile)
road type - 2L (two-lane)
M (multi-lane undivided)
F (freeway)

Table B-7 - Freeway Speeds (cont.)

SS#	A	Type of Work	Road Type	Activity	Speed Limit	No. of Observations (app. wk/ wk. area)	Mean Speed (c-app/wk area t-app/wk area)	85%
8	U	St. Stat	F	Guardrail repair	55	c 30/	c 55/	c 60/
						t 9/	t 53/	t 61/
9	U	St. Stat	F	Guardrail repair	55	c 41/	c 38/	c 44/
						t 9/	t 36/	t 40/0
10	R	St. Stat	F	Joint repair	55	c /71	c /46	c /54
						t /30	t /40	t /47
11	R	St. Stat	F	Bridgewashing	55	c 9/	c 42/	c 0/54
						t 3/	t 47/	t 0/41
12	U	St. Stat	F	Roto Milling	50	c /44	c /46	c 51/
						t /19	t /39	t 56/
13	U	Mov	F	Snow Plowing	55	c 47/	c 38/	c 43/
						t 42/	t 36/	t 42/
14	R	Mov	F	Stripping	65	c 53/	c 60/	c 66/
						t 17/	t 55/	t 59/
15	R	Mov	F	Center line stripping	55	c 50/6	c 37/34	c 43/35
						t 11/	t 37/	t 40/

c - car
t - truck

app. wk. - approaching work zone
wk area - near work area

A - area - R (Rural)
U (Urban)
type of work - St. Stat (short-term stationary)
Mov (moving)
Mob (mobile)
road type - 2L (two-lane)
M (multi-lane undivided)
F (freeway)

Table B-7 - Freeway Speeds (concl.)

SS#	A	Type of Work	Road Type	Activity	Speed Limit	No. of Observations (app. wk/ wk. area)	Mean Speed (c-app/wk area t-app/wk area)	85%
16	R	Mov	F	Asphalt overlay	65	c 140/ t 33/	c 38/ t 37/	c 48/ t 44/
17	R	Mob	F	Snow Blowing	65	c 6/21 t /5	c 67/57 t /58	c 64/64 t /60
18	R	Mob	F	Night Snow Blowing	65	c 4/ t	c 50/ t	c 50/ t
19	U	Mob	F	Pothole Patching	40	c 3/ t	c 34/ t	c 36/ t
20	U	Mob	F	Crack sealing	55	c 25/43 t 13/17	c 58/40 t 55/39	c 58/42 t 58/42
21	R	Mob	F	Crack sealing	55	c 20/27 t 8/34	c 55/50 t 53/50	c 59/56 t 58/55

c - car
t - truck

app. wk. - approaching work zone
wk area - near work area
A - area - R (Rural)
U (Urban)
type of work - St. Stat (short-term stationary)
Mov (moving)
Mob (mobile)
road type - 2L (two-lane)
M (multi-lane undivided)
F (freeway)Table B-5

Study 21 of Table B-7 - Freeway Speeds shows the hazard involved with crack sealing. Speeds of cars were only reduced 5 mph for cars and 3 mph for trucks from the approach to the work area. The reductions were found even when pedestrian workers were present for this operation. As shown in Study 20 of the same table, speed reductions were more substantial for crack sealing operation in an urban area. Many of the speed studies showed that trucks were normally traveling slower than cars on the approach but did not reduce their speeds as much as cars in the work area. This result agrees with many other speed studies made in work zones.

Appendix C

Industry Surveys

A survey of the present state-of-the-art in maintenance work zone technology was conducted to locate promising ideas and devices which already exist, to ensure that ideas and devices which already exist are not "reinvented" during the design competition, and to provide background for new ideas. Information on over 300 products applicable to maintenance work zones was requested through Roads and Bridges magazine's free reader request service. Information on approximately 300 products was received. This information was useful in providing an overview of maintenance work zone technology.

Letters were sent to professional organizations requesting recommendations for industry visits. A project summary was sent with these letters to help the organizations decide which firms would be most beneficial to the project. Table C-1 shows which firms were interviewed and persons visited in these organizations.

Firms were chosen for site visits based on the follow criteria:

* Does the firm represent an industry where safety problems have been observed?
* Is the firm considered representative of their respective industry?
* Is the firm innovative?

Table C-1

INDUSTRY VISITS

Company	Industry
1. Barrier Systems Inc. John Frank	Movable Barrier
2. Blaw-Knox Gene Goodwin	Asphalt Equipment
3. Carsonite Jim Newman	Traffic Control Devices
4. Clarkson Construction Safety and Security Ed DeMoss	Contractor
5. Emergency Service Co. Dennis Abbott	Safety Equipment and Clothing
6. Energy Absorption Mike Essex	Attenuators
7. Federal Mogul Rick Norland	Concrete Sawing Equipment
8. Master Builders Lisa Schuld Bob Gulyas	Set-45 Patching Material
9. Mickey Thompson Entertainment Bill Marcell	Water-filled Barriers
10. Namco Vick Noviski	Automatic Guidance
11. Poly Enterprises Al Provence	Self-righting cones

Because of these criteria, some recommended firms were not chosen for site visits, and some firms were chosen for site visits even though they had not been recommended by any professional organizations. Project personnel also attended the annual convention of the American Traffic Safety Services Association (ATSSA) where contacts were made for subsequent site visits. Listed below are some typical questions the project staff asked on visits.

* What do you see as the real safety problems in maintenance work zones where your products are used?
* Are your products being used as effectively as possible by maintenance personnel?
* What is your firm doing to make maintenance work safer?
* What are the alternatives to your product(s)?
* What aspect of your product(s) controls the speed at which maintenance operations take place.
* What improvements are in store for your products?
* Would your firm be interested in entering the design competition?
* What are the powers and pitfalls of your product(s)?

In general, the site visits and interviews were informative and enlightening. The interviews helped in identifying some safety problems and their causes, as well as identifying possible solutions to these and other safety problems. Table C-2 lists some of the important concepts and ideas that came out of the industry visits.

Table C-2

Industry Visit Conclusions

Interviewed Firm	Significant Points
1. Barrier Systems Inc.	* While BSI presently supplies the Movable Barrier, they envision providing a 350-ft long barrier that will move down the roadway with a maintenance operation.
	* BSI at present is not developing end-treatments for the Movable Barrier.
2. Blaw-Knox	* Resurfacing operation speeds can be more than doubled by trucks dumping asphalt in front of the paver on the ground rather backing up to the paver and dumping into a hopper.
	* The truck spotter on a paving operation is at the greatest risk of all maintenance personnel on the job.
	* For resurfacing operations, trucks have no formal traffic control to help them get back into traffic flow once they've dumped their load of material.
	* Automating the course depth adjustment function will reduce the number of maintenance personnel required on a resurfacing operation. However, the outsized dimension of the automating equipment precludes its use on some projects.
3. Carsonite	* Manufacturing feasibility is an important issue in evaluating possible new products
	* New ideas for products often come from field distributors, who upon seeing or hearing about a need for a new product, fill out a form describing a proposed product to meet that need. The marketing manager then makes the decision whether to proceed with development of the product, based on expected demand, cost, and expected effectiveness.

Table C-2 (cont.)

Industry Visit Conclusions

Interviewed Firm	Significant Points
	* Carsonite products are frequently misused or misapplied in the field. Overdesigning products helps them to perform adequately even when misused or misapplied.
	* Carsonite is interested in the design competition, but wants more specific information on patent rights and management of product development.
	* Carsonite believes that a combination of traffic control and positive protection is the best way to make maintenance work zones safer.
4. Clarkson Construction	* The constraining element on the rate of a resurfacing operation is the rate at which material can be delivered to the paver.
	* The most dangerous part of a resurfacing operation is the initial set-up and break-down of traffic controls.
	* Safety training of maintenance personnel has been an effective tool for reducing worker injuries.
	* Clarkson would prefer portable traffic signals in lieu of flaggers.
	* Sight distance and sign height are important issues in effective traffic control through work-zones.
	* It takes a minimum of 3 years to turn a contractors safety program around.
	* Traffic in general doesn't obey work zone speed limit signs.
5. Emergency Service Co.	* Good safety products exist that are rarely used, usually because of cost to the contractor or worker indifference.

Table C-2 (cont.)

Industry Visit Conclusions

Interviewed Firm	Significant Points
	* Enforcement is the best way to ensure usage of proper safety devices in maintenance work zones.
	* Hardhats do exist that are designed to stay on the head even when the wearer is bent over. However, there is room for improvement with these designs.
	* Contractors often won't train maintenance workers in safety.
	* Insurance companies are beginning to push contractors to work safer.
	* Flagger accouterments should be more "official" looking to help the flagger command respect.
	* Flaggers need long-handled paddles to prevent fatique.
	* Glare screen is effective in keeping oncoming headlights out of the eyes of motorists, and keeping motorists attention on the roadway.
6. Energy Absorption	* Energy Absorption is considering development of a snow-plow mounted attenuator. The main problem with designing one is that spreader designs vary widely, making it difficult to design a uniform attenuator.
	* Energy Absorption is in the process of developing a presentation to help explain roll-up of trucks with TMA's. According to Energy Absorption, total crush energy in a collision is the same with or without a TMA involved.
	* Energy Absorption is not interested in any project where the government would dictate product development. For good ideas, they'd rather do the development at their own expense.

Table C-2 (cont.)

Industry Visit Conclusions

Interviewed Firm	Significant Points
7. Federal Mogul	* Inconsistency in traffic control devices across the nation is confusing to motorists. * Rapidlane closures are dangerous to both motorists and maintenance workers. * Night work is dangerous because that's when the most drunks and fewest police are out. Also, drivers are more tired at night. * Quick setting materials are safer because they can be set at night, and the workers can be finished and off the roadway before morning traffic. * Not following standard procedures will create more work for maintenance workers. * Drunk drivers tend to drive toward lights at night. * Agencies usually send their most experienced people to professional meetings, such as ATSSA conventions. The people who need the training the most rarely get to go. * Dusk is the worst time for maintenance work because of rush hour traffic, sun in the eyes of motorists, and wandering minds. * Traffic slows only for the pinch in maintenance work zones; it will speed up past the pinch. * Speed bumps make traffic slow down. * Maintenance work needs to be coordinated with traffic patterns and public events. * Shadow vehicles and police in work zones are effective in protecting maintenance workers. * Trucks don't like to slow down or drive on shoulders because of steering and acceleration difficulties.

Table C-2 (cont.)

Industry Visit Conclusions

Interviewed Firm	Significant Points
	* Some equipment exists, such as stripers, that require workers to work on the lane lines. Special optics have been tried in order to get the workers off the lane-line, but up to now have not worked, mostly because workers can't depend on the optics.
	* Using flaggers can help make centerline operations safer, except at night.
	* Reflective tape on orange clothing provides good visibility for night work.
	* Hardhats are unnecessary for maintenance work where there are no overhead structures. Hardhats can even cause accidents by workers chasing them.
	* Weekly meetings between contractors, sub-contractors, and inspectors can help alleviate potential problems in work zones.
	* The government often specifies minority involvement in highway projects. As a result, contractors will often sub-contract traffic control to minority firms. Some of these firms are inexperienced, and therefore, traffic control is not as effective as it should be.
	* Federal Mogual would only be interested in the design competition if they were sure of an economic payback.
8. Master Builders	* Patches using special patching materials are often more durable than the surrounding concrete.
	* Set-45 patching material quality is fairly sensitive to component proportions and the mixing. Therefore, mechanical mixing is preferable to hand mixing of the components of Set-45.

Table C-2 (cont.)

Industry Visit Conclusions

Interviewed Firm	Significant Points
	* Traffic can be run over patches made with Set-45, forty-five minutes after the patch has been set.
9. Mickey Thompson Entertainment	* The Hydro-Barrier, a water-filled barrier is presently undergoing development in order to be used for highway maintenance work.
	* It takes anywhere from 1 1/2 to 2 1/2 minutes to pump out the water in one Hydro-Barrier section, depending on the pump.
10. Namco	* The idea of using an automated guidance system, such as Lasernet, to form a robot sign caravan for mobile work zones, is technically feasible.
	* Lasernet requires a target no further away than 20 ft for tracking. For roadway use, ground targets intermittently spaced would be the most effective reflector.
	* Lasernet has an out-of-view fail-safe pulse.
	* Lasernet costs approximately $3000/unit, and has a MTBF of 12,000 hrs.
	* Namco engineers recommend putting references, such as the MUTCD, in the prospectus for the benefit of those not familiar with work zone engineering.
11. Poly Enterprises	* Maintenance work on Los Angeles freeways is especially hazardous because of the extremely high traffic volume. Motorists even drive on shoulders to improve traffic flow.
	* The Daisy Cone, a Poly product is a self-righting cone. It is still considered an experimental device by the government, however.

Table C-2 (concl.)

Industry Visit Conclusions

Interviewed Firm	Significant Points
	* One shape to be considered for delineators is the arch, which presents a solid view when approached from the ends but is open, and therefore resistant to wind shear, from the side. * A brush type delineator has the advantage of popping back up after being run over.

Appendix D

Design Competition Details

Introduction

Based on the Task 1 results and a meeting of the Expert Task Group (ETG) where these results were discussed, ten design challenges were formulated into four categories. The four categories were based on reducing exposure to hazards and the following 1-2-3 system for increasing worker safety.

First, give adequate warning to drivers to make them aware of the work zone ahead. Secondly, warn workers if a vehicle is encroaching into the work area. Lastly, if vehicles encroach, provide barriers and other protection for workers.

The design challenges are shown below:

Category 1 - Improving Drivers' Understanding of the Maintenance Work Zone

- Area 1A - Improved Traffic Control Techniques and Devices for Advanced Warning and Transition area.

- Area 1B - Alleviation of Rear-End Collisions Between Traffic and Snow Plows or Salt Spreaders.

- Area 1C - Improved Flagging Techniques and Devices.

Category 2 - Effective Warning to Workers

Area 2 - Warning Devices for Maintenance Workers.

Category 3 - Effective Protection for Highway Workers

Area 3A - Protection of Pedestrian Maintenance Workers on the Roadway During Mobile Maintenance Operations.

Area 3B - Methods or Devices to Eliminate or Minimize Injury in Rear-End Collisions with Maintenance Vehicles.

Area 3C - Improved Safety and Protective Clothing for Pedestrian Maintenance Workers.

Category 4 - Open Category

Area 4A - Techniques, Tools, Equipment, or Materials to Remove, Substitute, or Lessen Exposure of Pedestrian Maintenance Workers on the Roadway.

Area 4B - Non-Accident Methods to Quickly Evaluate Traffic Control Devices, Lane and Route Guidance, and Training.

Area 4C - Devices for Special Maintenance Operations Including Nighttime or Emergency Work.

These design challenges were used as the basic categories for the Task 2 -Design Competition. The purpose of the design competition was to focus nationwide attention of the technical community on an effort to develop innovative devices and methods that will ameliorate maintenance work zone safety problems. The rules of the competition and background on each design challenge were published in a prospectus. This prospectus was mailed to over 600 persons.

By December 15, 1988, the final date for accepting proposals, 126 proposals were received. These proposals were reviewed and rated by the project staff and ETG.

This appendix documents the results of the design competition and ETG meetings.

Design Competition Ratings

Every design competition proposal was rated to determine its impact on alleviating highway maintenance safety problems. A ranking methodology was used to order the proposals. The methodology was used previously by the University of Tennessee in the FHWA contract "Identification of Traffic Management Problems in Work Zones," and by the project staff in the FHWA contract "Safety Restoration During Snow Removal." The methodology is simple in concept, but ensures that each device is rated on an equal basis, and that a number of raters with different backgrounds can use the methodology to furnish the most complete evaluation possible.

Each proposal was rated using the following six criteria, feasibility, usability, applicability, expected effectiveness, possible tradeoffs, and cost. Each of the criteria is defined as follows:

Feasibility - the level of technology involved in the concept. It ranges from presently unavailable technologies to technologies in common use.

Usability - a concept's ease of use by maintenance workers. It ranges from unusable concepts because of the education, experience, or expertise required; to concepts that require no special training or experience to use.

Applicability - how well the concept addresses the problem area. It ranges from concepts that can not be applied to the problem area because of roadway design constraints, temperature constraints, etc.; to concepts that can be applied to the problem area under all reasonable conditions.

Expected Effectiveness - involves the concept's ability to potentially mitigate injuries or deaths of maintenance workers. It ranges from a concept that neither saves lives nor reduces the number or severity of injuries of maintenance workers, to a concept that reduces 100% of the injuries and deaths of maintenance workers for the problem area.

Possible Tradeoffs - the level of undesirable side effects produced by a concept. It ranges from tradeoffs that disqualify a concept's use, to no tradeoffs which would adversely influence the concept's use.

Cost - the life cycle cost of the concept including development, fabrication, and maintenance costs of the concept. It ranges from a cost so high as to disillusion any potential buyers, to a low cost.

Proposals were rated by project staff and ETG members. The proposal evaluation process is shown in Figure D-1.

Proposals were rated by assigning a score of 0 to 4 to each of the six criteria (ranking factors). Table D-1 shows the proposal rating criteria used to assign scores to each criteria. The rater score for an individual rater was determined by multiplying the six criteria scores as shown in Table D2. This rating scheme results in a rater score of zero if any of the criteria scores are zero. For example, a proposal whose feasibility is rated as technically impossible would have a zero score no matter how other criteria were rated. Also, scores less than 1.0 reduce the overall concept ranking factor score.

All proposals were rated by at least three members of the project staff. The scores of all raters were averaged for each criteria and then multiplied to obtain an overall concept ranking factor or proposal score. The spreadsheet form used to compute these scores is shown in Table D-2 with example scores for Proposal Number 963.

H-108 "Maintenance Work Zone Safety"

Proposal Evaluation Process

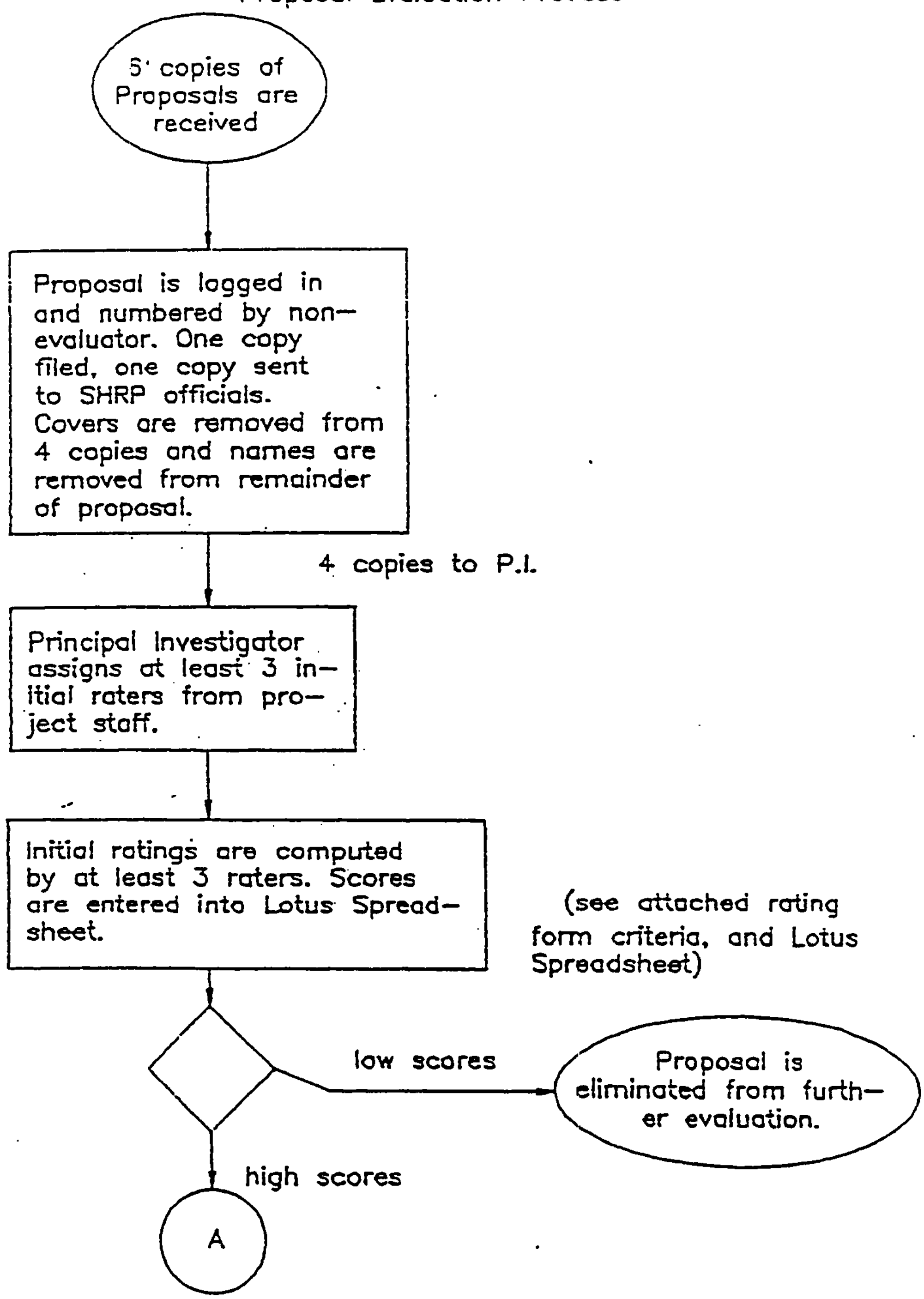


Figure D-1 — Proposal Evaluation Process

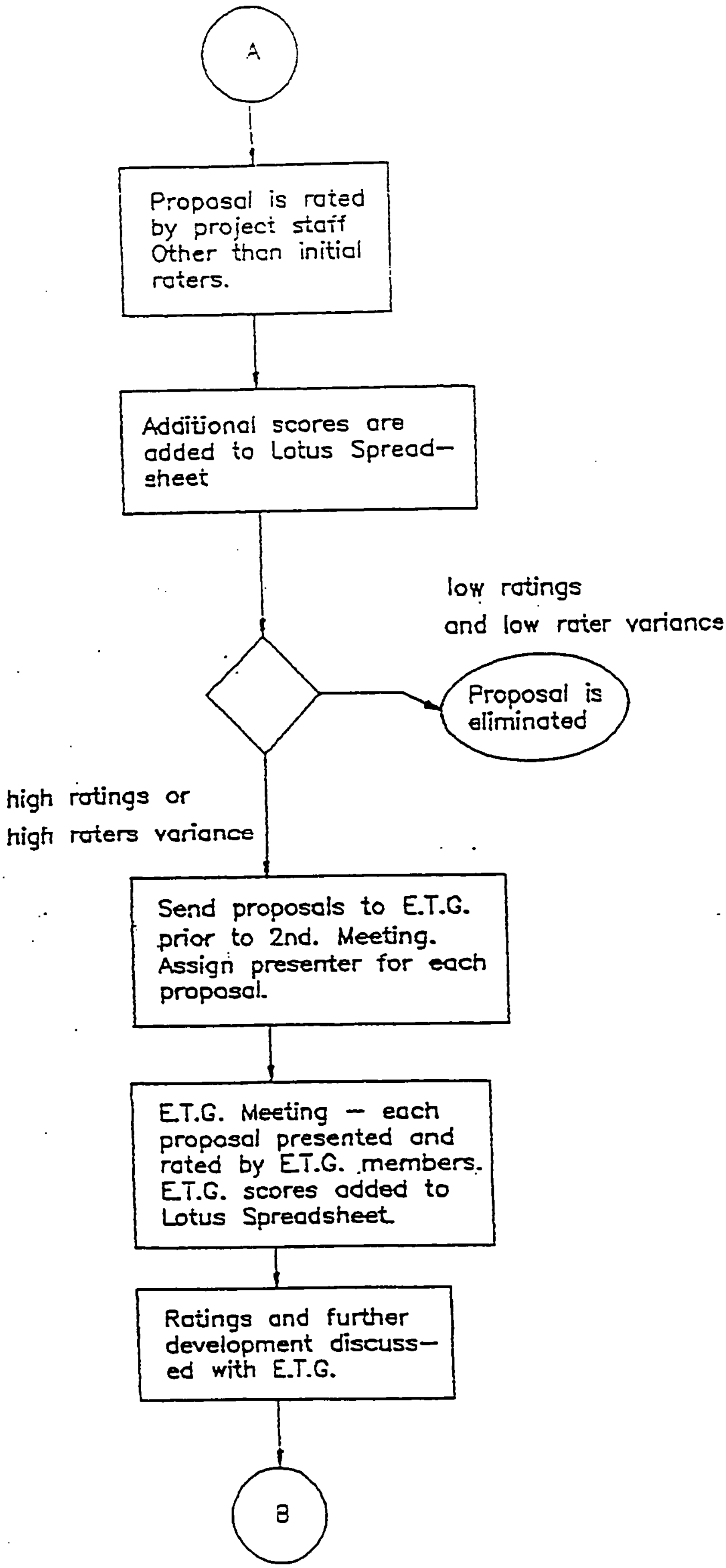


Figure D-1 – Proposal Evaluation Process (cont.)

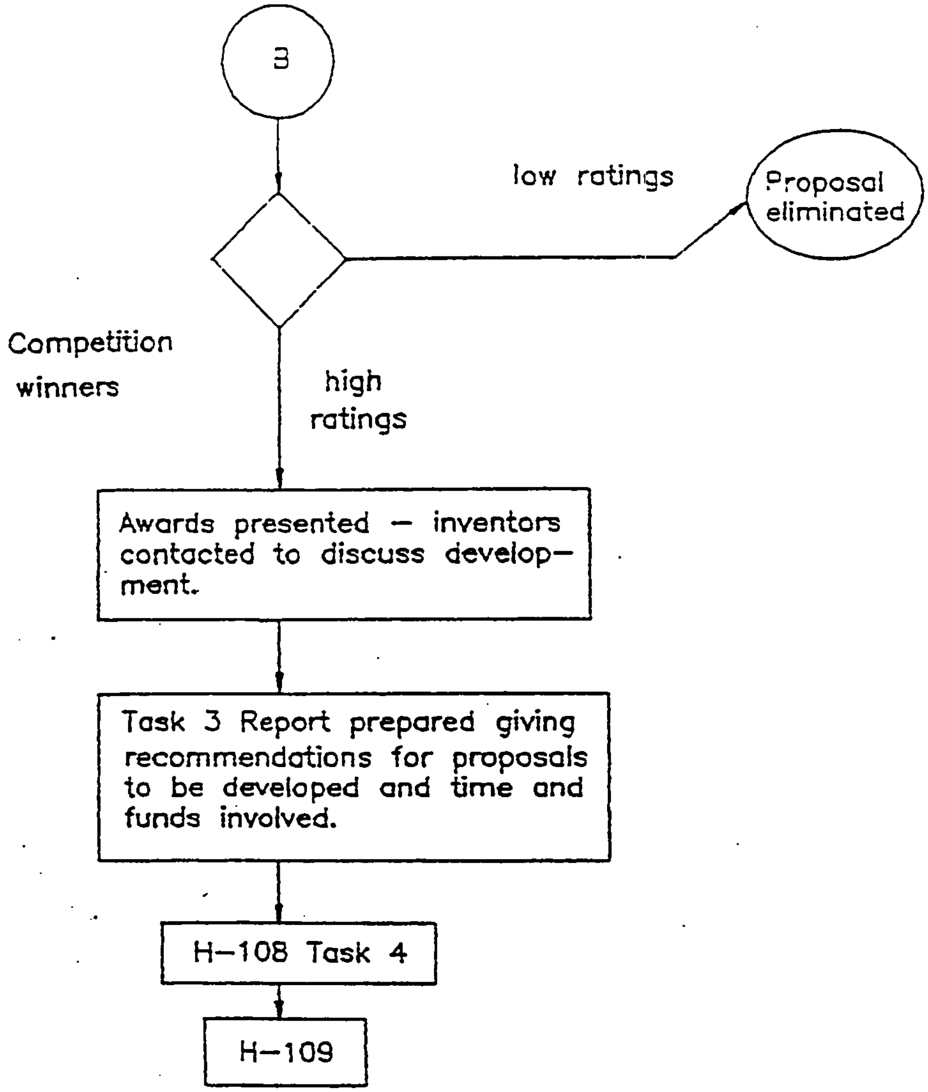


Figure D-1 — Proposal Evaluation Process (concl.)

Table D-1 - Problem Ranking Matrix

Feasibility (F) - the level of technology involved in the concept.

0 The concept is technically impossible, since it either involves non-existent technologies, or practices that are physically impossible (ex. perpetual motion machine).

1 The concept involves technologies or practices still in the experimental development stage (ex. "Star Wars").

2 The concept involves technologies or practices that are just beginning to be used in practical applications (ex. super-conductors).

3 The concept involves technologies or practices that are presently available, and have been used in a limited number of practical applications with success (ex. robotics).

4 The concept is based on technologies and practices that are presently available and in widespread use, even though they may not have been applied in this manner before (ex. automotive technology).

Usability (U) - a concept's ease of use by maintenance workers as compared to the education, experience, and physical abilities of most maintenance workers.

0 The concept is not usable by any personnel due to education, experience, or expertise required.

1 The concept may require personnel with different education or experience than normally available in maintenance groups.

2 Maintenance personnel can use the concept with proper extensive training.

3 Maintenance personnel can use the concept given a brief introduction and orientation to the concept.

4 The concept is usable by most personnel currently employed in State or local maintenance units with no prior specialized training or orientation.

Table D-1 - Problem Ranking Matrix (cont.)

Applicability (A) - how well the concept addresses the problem area, by comparing the concept's function and capabilities to the operating conditions of the problem area.

0 The concept cannot be applied to the targeted problem area under any conditions.

1 The concept can be applied to the targeted problem area once in a while given proper physical or institutional conditions.

2 The concept can be applied to the targeted problem area half of the time given proper physical or institutional conditions.

3 The concept can be applied to the targeted problem area most of the time given proper physical or institutional conditions.

4 The concept can be applied to the targeted problem area under any reasonable condition at any time.

Expected Effectiveness (EE) - the concept's ability to mitigate the injuries or deaths of maintenance workers.

0 The concept will not eliminate injuries and death for the problem area at all.

1 The concept will eliminate a few injuries and deaths for the problem area.

2 The concept will eliminate half of the injuries and deaths for the problem area.

3 The concept will eliminate most injuries and deaths for the problem area.

4 The concept will completely eliminate injuries and deaths for the problem area.

Possible Tradeoffs (PT) - the level of undesirable side effects produced by a concept.

0 The concept has tradeoffs that disqualify it's use.

1 The concept has tradeoffs that adversely affect it's performance most of the time

2 The concept has tradeoffs that adversely affect it's performance half of the time.

Table D-1 - Problem Ranking Matrix (concl.)

3 The concept has tradeoffs that adversely affect it's performance once in a while.

4 The concept has no tradeoffs that adversely affect it's performance under any reasonable conditions at any time.

Cost (C) - the life cycle cost of the concept, including development, fabrication, and maintenance costs of the concept.

0 Cost is prohibitively expensive and would disillusion all potential buyers.

1 Cost is high and would disillusion most potential buyers.

2 Cost is moderate and would disillusion half of the potential buyers.

3 Cost is low and would disillusion a few potential buyers.

4 Cost is negligible and would disillusion no potential buyers.

Table D-2

Graham-Migletz Enterprises, Inc.
SHRP Project 87-108
Design Competition Concept Evaluation

Proposal Number: 963
Design Category and Areas: 1C
Concept Title: Power Flag

Proposal Score: 618.1

Ranking Factor	Raters and Scores										Statistics by Ranking Factor		
	1 JLG	2 JM	3 JL	4 RM	5 JCG	6	7	8	9	10	Mean	Std Dev	Var
Feasibility	3.5		3.0		4.0						3.5	0.4	0.2
Usability	3.0		2.5		3.5						3.0	0.4	0.2
Applicability	3.0		4.0		4.0						3.7	0.5	0.2
Expected Effectiveness	1.8		2.0		3.0						2.3	0.5	0.3
Possible Tradeoffs	3.5		2.0		3.0						2.8	0.6	0.4
Cost	2.5		2.0		3.0						2.5	0.4	0.2
Rater Score	496.1		240.0		1512.0						618.1 = Proposal Score		

Proposals with consistently high proposal scores were selected for rating by ETG members. Proposals with consistently low proposal scores were rejected from further consideration. Proposals with mixed scores that exhibited a great deal of variability were rated by one or two additional project staff members and then sent to the ETG or rejected based on the overall proposal score.

Each ETG member received 63 proposals, one to two weeks prior to the second ETG meeting. At this meeting each proposal was described by a staff member. After questions were answered and the proposal discussed, each ETG member rated the proposal using the same rating procedure.

The purpose of the competition was to encourage the development of "new" concepts. Proposals were to contain concepts of devices, materials, or techniques not in current use. "In current use" was defined as a device that has be prototyped and tested and is developed and available for sale.

During the rating process, it was determined that 13 proposals described devices that were already "in use." The 13 proposals were eliminated from the competition.

The rating process and ETG meeting resulted in the decision to make cash awards to the top 37 concepts. Concepts rated 1-3 were awarded $2,000; concepts 4-7 were awarded $1,000; and the remaining thirty concepts were awarded $500 each.

The proposals are grouped according to eight "study areas" described below.

Staff and ETG Ideas

Solutions to safety problems were mainly to come out of the design competition. The project staff and ETG, because of closeness to and everyday association with the safety issues in this project, brainstormed a number of devices to help solve the observed safety problems. Table D-3 presents staff and ETG ideas for new devices. The staff and ETG ideas are of particular importance since some categories of the design competition did not generate many responses, especially protection devices. New protection devices are absolutely essential and needed if maintenance worker safety is to be improved, and the state-of-the-art of maintenance work zone safety advanced. For this reason, most (4 out of 7) of the staff and ETG ideas are in the barrier design area. By combining the staff and ETG ideas with the design competition ideas, a full range of promising concepts was available for development.

Descriptions and sketches of each of the staff and ETG ideas are shown in the appropriate study area grouping. (Appendices E-K)

Table D-3

H-108 Staff and ETG Ideas

Concept Number		Title	Study Area
SI1	-	Personnel Protection Trailer	1
SI2	-	Movable Barrier End Treatment	1
SI3	-	Reusable TMA	1
SI4	-	Snow Plow TMA Interface	1
SI5	-	Flagger Gate	6
SI6	-	Moving Taper	4
SI7	-	Diverging Lights	5

Study Areas

A large number of design competition proposals were seen as promising. These concepts plus the E.T.G. and Staff Ideas were grouped into 8 study areas based on the type of device and development effort required. These areas are shown in Table D-4. The overall goal of each of the study areas is to develop a device that can be commercially provided for use by maintenance forces in the U.S. or any foreign country. Implementation packages that give guidelines and procedures for correctly using the device are also included in each of the study areas.

Table D-4

Task 4 Study Areas

Area 1-Barrier Design

855 - Tote Trailer for Sand Barrels
317 - S.CAI Barrier
SI1 - Personnel Protection Trailer
SI2 - Movable Barrier End Terminal
SI3 - Reusable TMA
SI4 - Snow Plow TMA Interface

Area 2 - Warning Device Prototypes

506 - Work Area Intrusion Alarm
810/807 - Personnel Early Warning System
843 - Life Saver
739 - The LookOut
108 - Early Warning Device
692 - Infrared Errant Vehicle Detector
912 - Infrared Queue Length Detector
670 - Portable Protective Warning System
270 - Buffer Zone Alert System

Area 3 - Rumble Strip Fabrication and Testing

118 - Work Zone Rumble Strips
933 - Portable Traffic Warning Speed Bumps
187 - Portable Rumble Mat
287 - Safe Speed Reduction Mat

Area 4 - Delineation Device Fabrication and Testing

310 - Opposing Traffic Lane Dividers
002 - Direction Indicator Barricade
990 - Fiber Optic Caltrop
579 - Retractable Transition Device
941 - Portable Soft Barricade System
156 - Delineator Hose
SI6 - Moving Taper

Area 5 - Lighting Device Testing

068 - The Guiding Light
172 - Snow Plow Blade Markers
049 - Attentive Signing Device
918 - Police Light Assembly
319 - TROTAR
SI7 - Diverging Light

Table D-4 (concl.)

Area 6 - Sign Fabrication and Testing

032 - Portable Sign Stand and sign
999 - Flow through Stop and Slow Paddle
161 - Flashing Stop/Slow Paddle
SI5 - Flagger Gate
467 - Truck Mounted Message Box
875 - Alternate Merge Signs

Area 7 - High Potential-High Risk Concept Development

890 - Automatic Mobile Warning Vehicles

Area 8 - Testing of Promising Concepts

832 - Brooks Pavement Marking Device
654 - 3 Way Dump Body
898 - Helmet Liner

Appendix E

Barrier Designs

Introduction

Six positive protection devices comprise the barrier design study area. The S.CAI Barrier is a New Jersey shaped water-filled barrier designed for rapid deployment and retrieval.

The Personnel Protection Trailer is a semi-trailer towed by a maintenance vehicle, and is designed as a portable barrier for pedestrian maintenance workers. The trailer has expandable, reinforced steel vertical panels on it's sides to form the barrier wall, with the space in-between the walls forming a protected work area.

The Movable Barrier End Treatment is an end-treatment designed to be used with the Quickchange™ Movable Barrier System. The end treatment consists of a system of crushable metal barrels fastened to the barrier system. This system is very similar to the Connecticut Narrow Impact Attenuator.

The Aluminum Can Truck Mounted Attenuator (ACTMA) is a truck-mounted attenuator with an array of empty aluminum drink cans forming the attenuation mechanism. It is designed to be a cheaper and lighter version of present TMA designs.

The Salt-Spreader/TMA Interface is a tubular structure designed to facilitate the mounting of commercially available TMA's to rear-spreading salt spreaders.

The Portable Crash Cushion is a straddle carrier designed to carry a complete sand barrel crash cushion array on a platform. The carrier is used to quickly move a crash cushion into a closed traffic lane upstream of a maintenance operation for in-lane protection of maintenance workers.

The eleven tasks seen as necessary to development of these barriers are shown in Table E-1 - Tasks for Barrier Design. Tasks 1-5 were conducted in Project H-108 and Tasks 6-11 will be conducted in Project H-109.

The intent of Project H-109 is to take the prototype plans developed in Project H-108, and develop them into working field models. The fabrication of the six prototype barrier devices will be done at the beginning of Project H-109. The prototype devices will then be tested under expected field conditions, including crash tests, maneuverability tests, etc. Evaluation and final design will include any necessary modifications to the prototype devices based on the results of the tests. Field trials will then be conducted and will involve the experimental use of the modified, prototype devices by actual maintenance forces. Finally, implementation packages will be developed for each device, including operator's manuals, traffic control plans, etc.

Table E-1

Tasks for Barrier Design

Task 1 - Design and Performance Criteria	Establish design and performance criteria for device.
Task 2 - Value Analysis and component Design	Design and optimize the various device components.
Task 3 - Component Integration	Integrate the various device components to form a unified prototype device.
Task 4 - Theoretical Analysis	Predict the devices performance under various impact conditions.
Task 5 - Final Prototype Design	Modify the design, if necessary, based on the Theoretical Analysis. Draft the final prototype design for fabrication.
Task 6 - Prototype Fabrication	Fabricate a prototype device for testing purposes.
Task 7 - Testing and evaluation	Perform crash, maneuver, and operational tests of the device, and evaluate the test data.
Task 8 - Final Design	Modify the design of the device based on the test evaluation.
Task 9 - Final Fabrication	Fabricate a modified device for field trial purposes.
Task 10 - Field Trials and Evaluation	Use the device in actual maintenance operations and evaluate the field performance.
Task 11 - Implementation Package Concept Report	Develop an implementation package for the device and write a final concept report.

The S.CAI System

Background & Device

The S.CAI system uses reinforced plastic composite (RPC) as the main material in the construction of modules. The possibilities of pigmentation and coloring of this material are well known in the technical field. In this case, white is the most appropriate color. The modules are also fitted with reflective strips and small reflectors.

The mold is 2 meters (6.5 ft) long and weights approximately 20 kg (44 lb). The barrier has the New Jersey safety shape profile and is 80 cm (31.5 in) high. There are both male and female sections. The sections have steel rods to maintain tension throughout a run of barrier. Drawings of the male and female sections of the barrier are shown in Figures E-1 and E-2.

A barrier made of white polyester would contrast well with its surroundings (black or dark grey asphalt) and is visible both day and night. The reflectors fitted in the barrier during its manufacturer also improve visibility.

Barriers, in areas of fog or snow, can be fitted with red strips on the upper side part of the module providing a greater contrast and better visibility.

The cost of each module is based on the current prices is Spain ($1.00 = 130 pesetas).

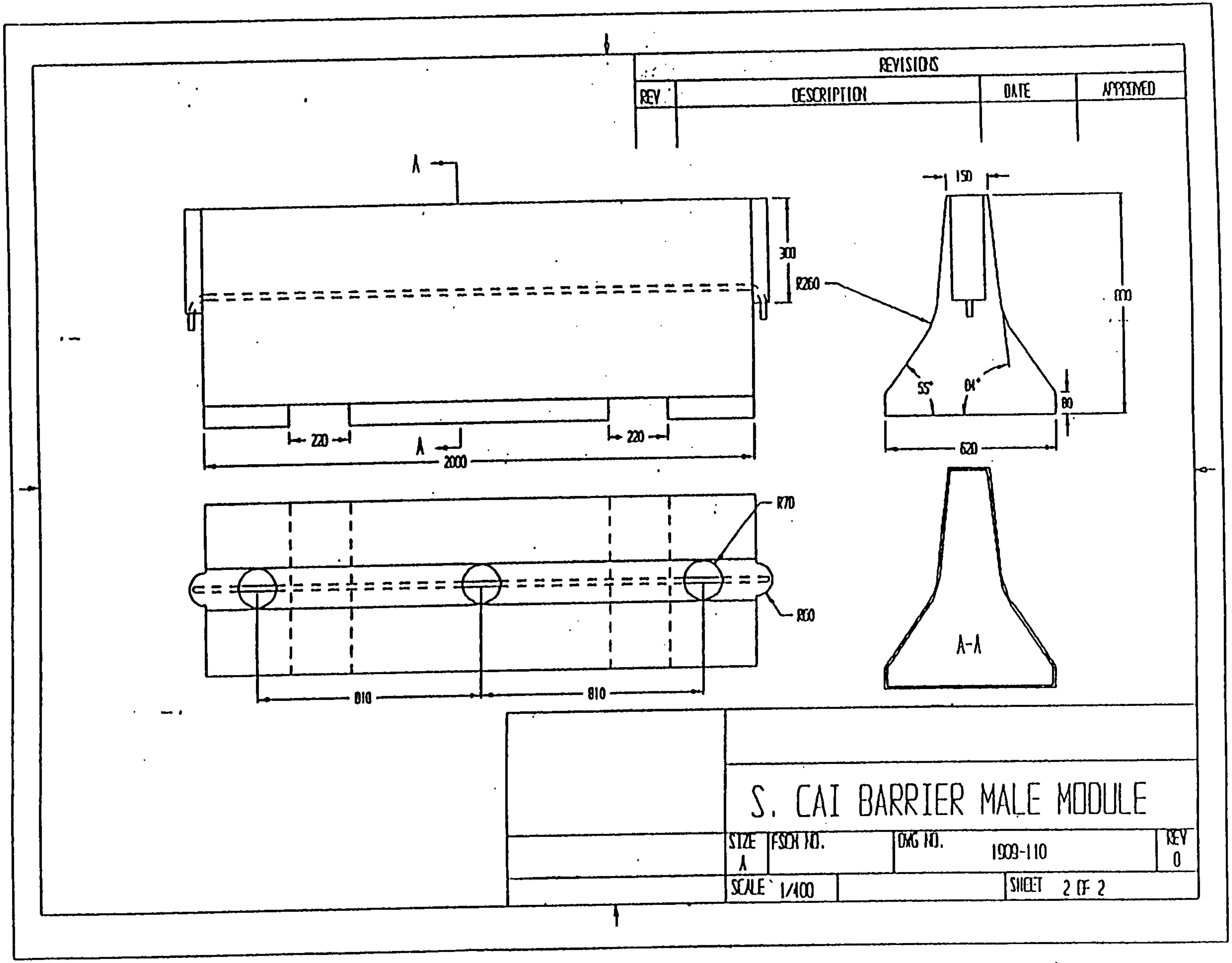


Figure E-1 - Male Section - S.CAI Barrier

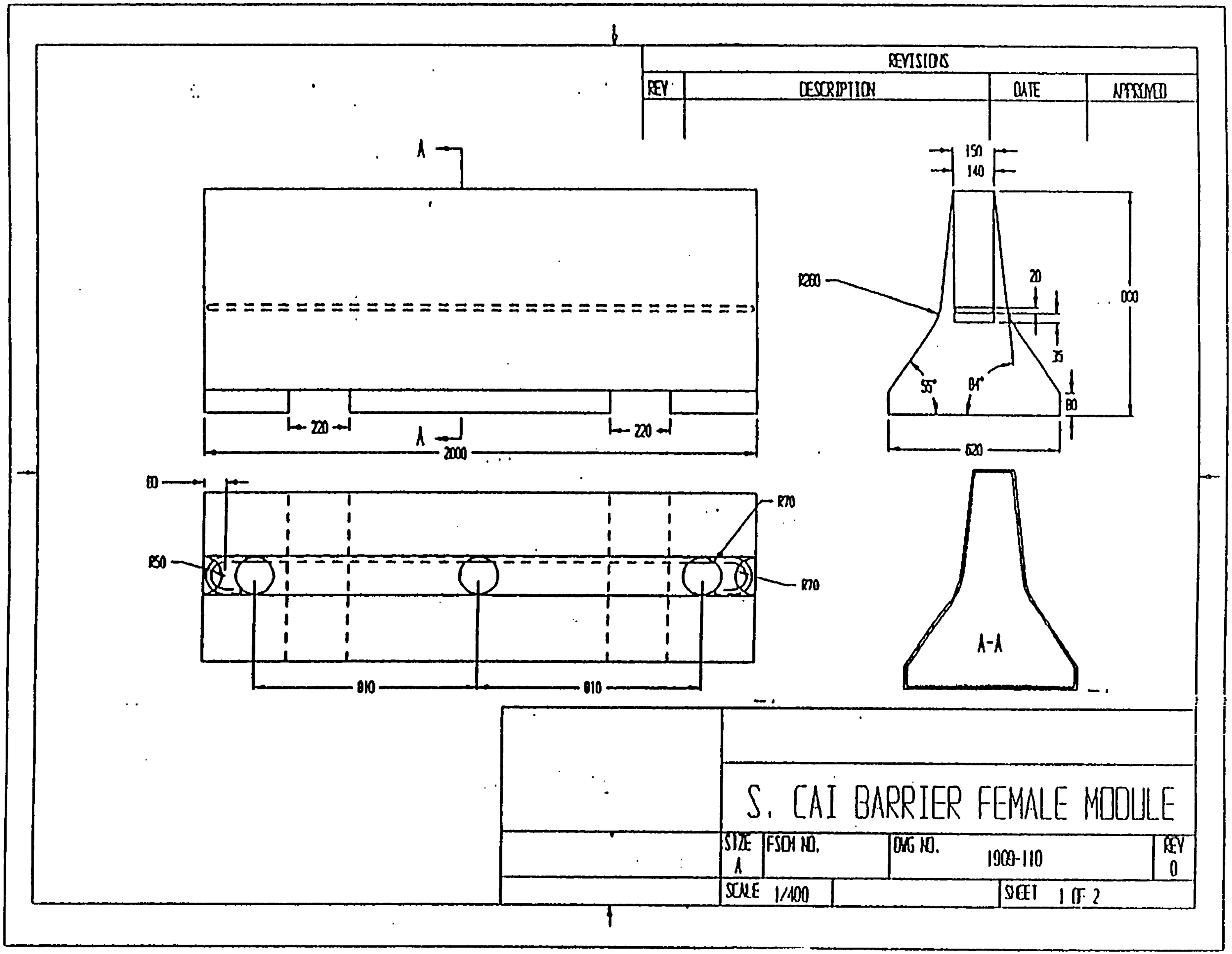


Figure E-2 - Female Section - S.CAI Barrier

The finished factory prices, not including transport, is 10,000 pesetas per module or 5,000 pesetas per linear meter ($77 per module, $12 per foot).

The production capacity is from 75,000 to 100,000 meters/year.

As the molds weight only 20 kg, they can be stored by stacking one on top of another to a height of 4 meters (8 layers).

Using a standard flatbed tractor-trailer, 170 meters can be transported.

Installation

A 2- or 3-man crew can install and position the empty barriers. The positioning time is 1,500 meters per day using three men.

There are no installation requirements that are special in relation to the plastic barrier. Vehicles to haul the desired fill material are required.

When the modules have been positioned, they can be filled with concrete, for permanent installations, or sand or water for temporary installations.

Concrete-filled modules

Concrete is placed in the mold through the openings in the top of the mold. When the modules are filled, they weigh the same as the precast concrete molds, which is 1270 kg (2800 lb).

The filling time is 250 meters per day (125 modules) using a two-man crew. The system permits several working areas to be opened along the barrier without causing any type of problem. Each module will hold approximately 0.75 yards of concrete.

The manufacturer states that the concrete should be smooth in texture to avoid the use of vibrators in the filling process.

Sand-filled modules

The sand fill material is also placed in the module through the openings in the top of the mold. When the modules are filled, the weight is approximately 1000 kg (2200 lb). Each module will hold approximately 0.75 yards of sand.

The manufacturer states that it is preferable to use dry sand which eases the filling of the modules and that fine gravel can also be used.

With sand, the modules weigh 77 percent of standard concrete barriers. However, for temporary installations, filling with sand and, especially, removing the sand will be a slow process. Also, in the event of a vehicle damaging a module, the sand will spill onto the road and have to be removed.

Water-filled modules

With water as the fill material, the modules weigh approximately 560 kg (1220 lb). The modules are easily filled and can be as easily emptied through valves positioned on the bottom of the module.

Filled with water, the modules weigh 43 percent of standard concrete barriers. Each module holds approximately 150 gallons.

There is a problem as to where to drain the water. It may be possible to use hoses to carry the water away from the roadway or the work site and into a drainage area. Also, repeated use of the modules may result in small leakages or holes. However, the modules should be easily and cheaply repaired.

Maintenance

With the exception of maintaining the water level in water filled sections and replacing reflectors, no usual maintenance is required.

In an emergency maintenance/repair situation, the damaged sections must be replaced and refilled with the desired fill material and the fill material and debris must be removed. Some heavy equipment will be required for removal of concrete-filled and sand-filled sections.

Removal

Removal of water-filled sections is easily accomplished as noted previously. The water is drained and then the sections are easily moved by a two-man crew.

The sand can be removed but is probably easier to transport the sections full. This movement will require more labor and heavy equipment.

Personnel Protection Trailer

The Personnel Protection Trailer (PPT) is a semi-trailer hinged to the rear and towed by a bobtail tractor and is used in pavement maintenance operations such as pothole patching. It is designed to protect pedestrian maintenance workers from errant vehicles. The PPT consists of a hinge assembly in front, wheel assembly in rear, and reinforced vertical steel panels forming it's sides. The area between the reinforced panels, and between the hinge and rear wheel assembly is open, and is for the purpose of forming a protected work area for pedestrian maintenance workers. Figure E-3 shows the PPT.

The PPT is 8 1/2 ft wide for transportation purposes, with the walls hydraulically expanding and locking to either 10, 11, or 12 ft wide for roadway maintenance operations. It is 65 ft long and weights approximately 60,000 lbs to help minimize lateral deflection when hit by an errant vehicle. The aluminum

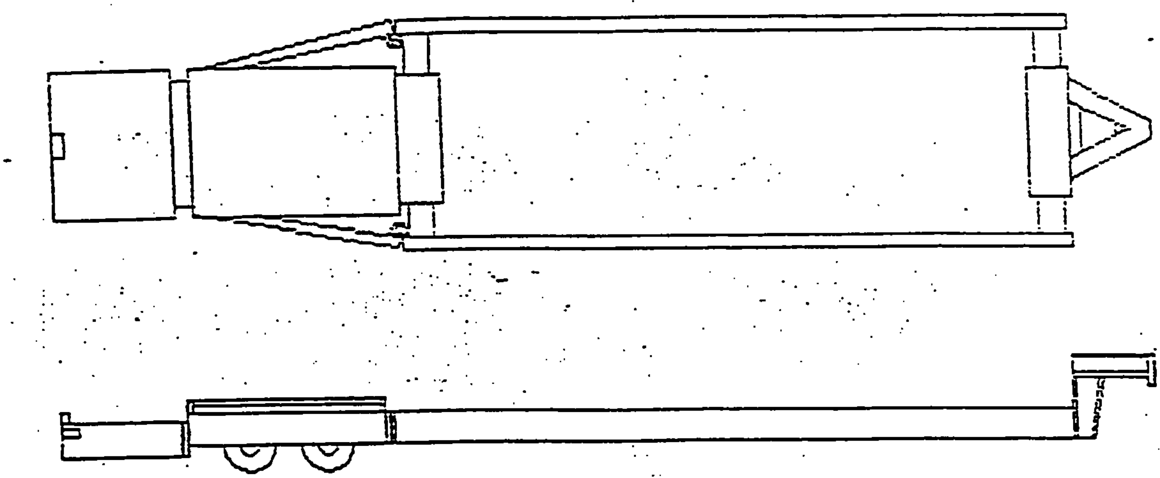


Figure E-3 - Personnel Protection Trailer can TMA (described later) is attached to the rear of the trailer. However, this feature is still in question since TMA's are designed to be used with vehicles weighing between 10,000 lbs to 24,000 lbs in order to work properly. The side walls of the PPT are 7-in thick, 24-in high, and 18-in off the ground.

The PPT also has a material box insert that attaches to the front hydraulics housing unit. The material box is for carrying patching materials, tools, and other items or materials workers may need when working on the roadway.

Testing of the PPT should include maneuverability tests, operational tests, and crash tests. Maneuverability tests should be conducted on a closed track to determine how the PPT handles at highway speeds, and for a variety of turning and braking maneuvers. Operational tests should include simulated maintenance operations on a closed track using the PPT to see how easily workers can work within it's walls. At least one crash test with a 4500-lb vehicle at 60 mph and 25° should be conducted, with the impact point being one-third of the wall length back from the front-end of the wall. This test should be conducted in accordance with Test No. 10S of NCHRP 230.

Moveable Barrier End Terminal

Background & Device

The Moveable Barrier System is a hybrid system of the concrete median barrier system. It is similar in profile to a CMB and constructed of concrete. The units are approximately 3 ft long and are connected with a link pin. The unique design feature to this concept is they can be moved laterally with a machine in a continuous motion, and quite quickly. This makes this system very adaptable to a short term work zone environment. To date, these systems have been deployed using no terminal on the end. Instead, sand barrel arrays are set in place with fork trucks, or the barrier system is tapered back along the roadway. To obtain a terminal which is crash-worthy and meets the needs of a short-term work zone, a quickly deployable system is needed for the terminal.

Currently, the manufacturer of these devices does not make an end terminal. They have explored the possibility of flaring the last few elements away from the roadway, but to date have not qualified this concept in accordance with NCHRP Report No. 230. The Movable Barrier End Terminal is a new concept for terminating the moveable barrier using steel tubes like those on the Connecticut Narrow Impact Attenuator. The major component of this concept, the steel tubes, have been crash tested in accordance with NCHRP 230, and found to be crash-worthy. The basic approach was to adapt the Connecticut Narrow Impact Attenuator to the end of the moveable system. The Connecticut system is comprised of a series of eight 3-ft diameter steel tubes, tied together with four steel cables. The overall length of the system is 24 ft. The tubes are 4 ft tall. A special adaptor has been designed to connect the last steel tube to the concrete barriers as well as anchor the rear end of the guide cables. The forward end of the guide cables have a requirement to be anchored to the pavement to prevent the system from collapsing due to a side impact. This is accomplished using an anchor box which is cast into the pavement. Chains are attached to the end of the guide cables at the forward end of the cables. The forward end of the chains are passed through the anchor box and back onto themselves, at which point a grab hook is used to attach the chain end to the chain body. All four cables are attached in a similar manner. The system is depicted in Figure E-4.

Installation

Installation of this terminal for the first time will require assembly of the entire unit. The following steps are required.

1. Bolt all eight tubes together using supplied 0.875-in hardware. Insure order of tubes correct, (check wall thickness and internal bracing).

2. Install internal braces
   tube 1 - 0.5-in cross rods
   tube 5,6, & 7 - compression strut
   Tube 8 - tension strut.

3. Attach adapter bracket to tube 8.

4. Thread cables through holes and attach to tubes using U-clamps.

5. Attach chains to end of wire cables.

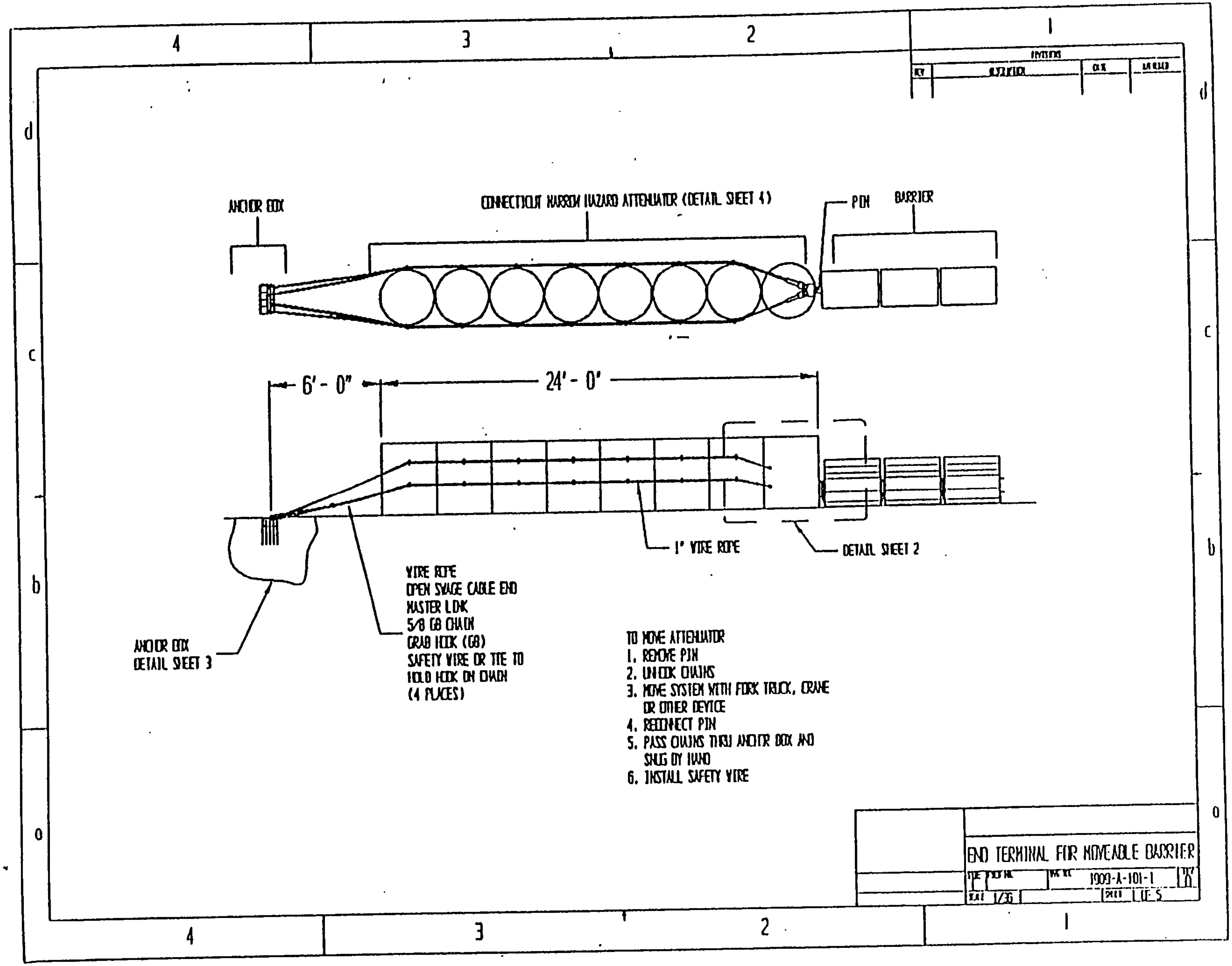


Figure E-4 - End Terminal For Moveable Barrier

6. Move system into place using truck to slide around or small crane to lift and place. (Also fork truck could be used).

7. Install anchor box in location as indicated on assembly drawing. Allow concrete to obtain strength. (Use of High Early or similar product may be used to speed concrete cure time).

8. Attach chains to chain anchor boxes by passing chain around the round bar in top of box. Pull chain tight and hook on itself. Secure hook with tie wire or tie wrap.

As moveable barriers are transferred there tends to be some slip of the barrier modules along the roadway, thus the end does not end up in the same place between moves from a given place and back again. To account for this shift, the chains have sufficient length to allow for hooking near the anchor box all the way up to the adapter between the chain and cable. On occasions where there is not sufficient length to hook the chain or excess length to prevent a tightly hooked chain, then modules should be added or removed from the movable system to obtain the correct length.

Transferring

The end system is transferred prior to transfer of the moveable barrier system. this is required because the tube assembly will not pass through the transfer vehicle. The system is prepared for transfer by disconnecting the chains from the anchor box and removing the link pin between the first barrier module and the last tube in the Connecticut attenuator assembly. These two steps fully disconnect the terminal from the barrier and allow it to be moved. To relocate laterally only a few feet the system can be slid using a pickup truck and a chain to pull it with. Also a small crane could be used for this move. To move longer distances, the system can be loaded as a whole using a crane and transported with a 24-ft truck. It can also be broken into smaller modules and moved with a 12-ft truck.

In cases where the system must be crashworthy in its second location i.e. not placed out of service by the move, a second anchor box will need to be installed for connection of the chains. After completion of use of the terminal the anchor box should be removed, and the sub-grade returned to a condition similar to that of the surrounding area. The anchor box could be left in place and covered if determined acceptable by the site engineer.

Maintenance

Very little maintenance is required for this terminal. Occasional painting is required to prevent rusting. All pin joints should be checked to ensure pins are connected correctly. The four guide cables need to be checked to ensure no broken wires or strands are present.

If the system is impacted, all bent tubes should be replaced. The cables are reusable, assuring there are no broken wires or strands. All pin joints should be checked to ensure proper operation.

Aluminum Can Truck Mounted Attenuator

The Aluminum Can Truck Mounted Attenuator (ACTMA) is a truck mounted attenuator consisting of an array of empty aluminum drink cans to form the attenuator mechanism. It is designed to provide a crash cushion between maintenance vehicles and traffic in rear-end accidents. The advantage of this device is that it will cost less and weigh less than presently commercially available TMA's. Figure E-5 shows the ACTMA.

A series of crush tests were performed on empty aluminum drink cans to determine their energy absorbing capacity. This data was used in a systems dynamics analysis where the cans were modeled as an array of perfectly plastic springs both in series and in parallel. Based on this analysis, an optimum arrangement of the array of cans was determined so that the ACTMA will perform similar to commercially available TMA's during impacts.

The ACTMA aluminum can array is 9 cans high, 38 cans wide, and 17 cans deep. Each individual can is 4 3/4-in high and 2 1/2-in in diameter. The cans are arranged so that the longitudinal axis of each can is parallel to the line of impact of the TMA for a 0° impact. The cans are arranged in nine layers, with each layer of cans placed in a cardboard tray. The nine trays are stacked vertically, and are collectively wrapped in a burlap shroud. The wrapped array is then placed in a fiberglass shell, which is sealed using 1/4-in nuts and bolts. The ACTMA is attached to the maintenance vehicle by four mounting studs

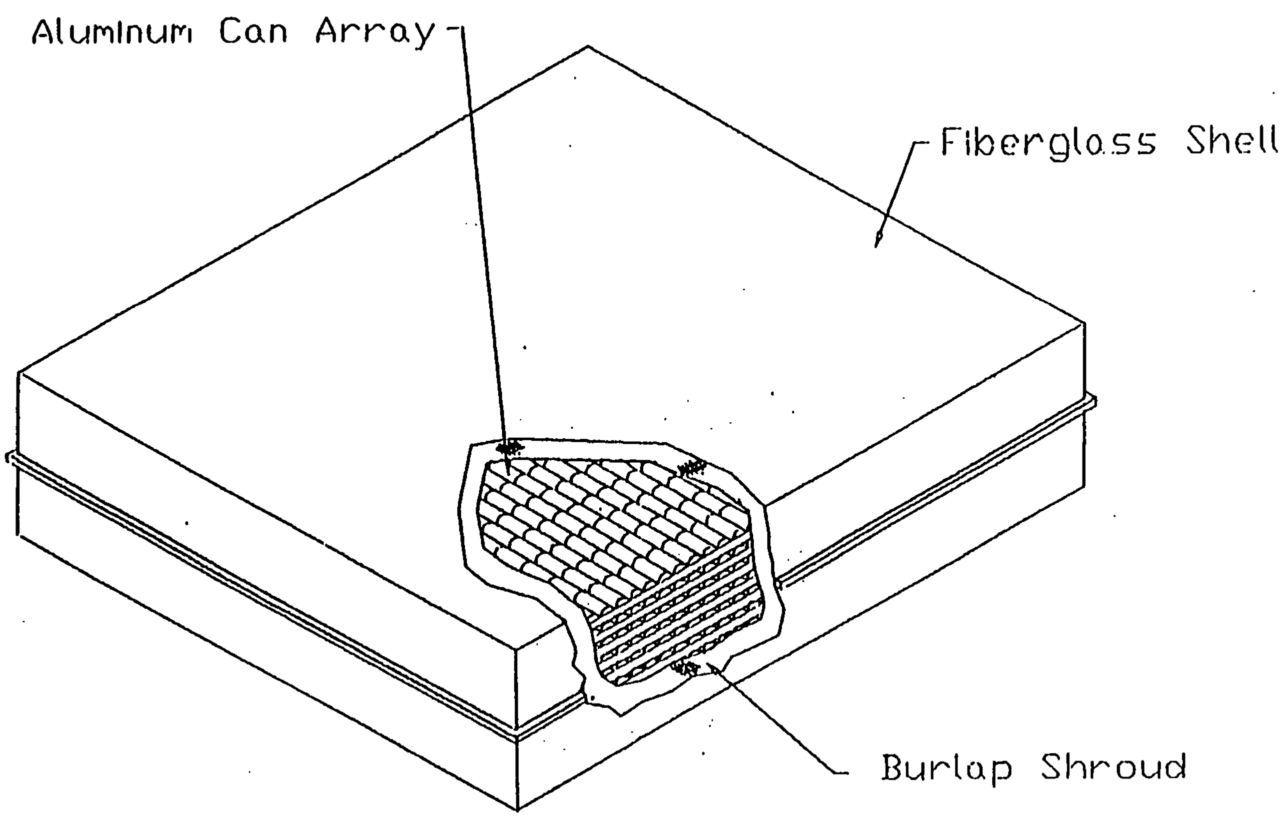


Figure E-5 - Aluminum Can Truck Mounted Attenuator on the truck side of the ACTMA. In all other respects, the ACTMA is designed to function and operate the same as other commercially available TMA's. One conceivable scenario for the fabrication of the ACTMA is that State DOT's could manufacture their own units by collecting aluminum drink cans in house, purchasing the other materials, and then assembling the ACTMA.

Testing of the ACTMA should include and meet all impact tests called for in NCHRP 230, as well as vibration tests and corrosion tests. The impacts tests should be for both a 5400-lb vehicle and a 1600-lb vehicle, each impacting head-on at 45 mph. Two vibration tests should be performed to determine the ACTMA's ability to withstand the vibration associated with travelling. Each test should have a frequency of 5-8 HZ, and excursion on 0.60 $\pm$ 0.05-in, and 40 hours for each test. The same article should be used for both tests. The article should be essentially undamaged after the vibration tests. The moisture test will involve spraying the ACTMA with salt water at a rate of 6-in of water per hour. The ACTMA should be sprayed for 24 hours on both it's top and both sides and then checked for corrosion damage and moisture retention.

Salt Spreader/TMA Interface Structure

The Salt Spreader/TMA Interface Structure is a steel tubular frame structure designed to be an adapter between rear-spreading salt spreaders and commercially available TMA's. While TMA's do not eliminate rear-end accidents, they do lessen their severity. However, because of interference problems with present designs, TMA's can not be used with rear spreading salt spreaders.

The Salt Spreader/TMA Interface Structure is a modification of current TMA mounting hardware designs. The difference is that the Salt Spreader/TMA Interface Structure has an opening in it's center through which the salt spreader spinner assembly can drop through the interface. All structural and hydraulic members are mounted on either side of the spinner assembly opening. Figure E-6 shows the interface structure.

The size of the opening is adjustable to accommodate different spreader assembly sizes. The interface structure also has a hydraulics package for tilting the TMA for transport. For warm weather use, when the salt spreader is not mounted on the truck, the interface structure compresses to approximately the same size as current TMA mounting hardware designs. This mounting feature permits the TMA to be used year round.

One possible drawback to the Salt Spreader/TMA Interface Structure is that in order to create the necessary clearance for the spinner assembly, the TMA may be cantilevered further from the rear of the truck than is typical with current TMA designs. Hence, a hyper-extended TMA may create some maneuverability problems for salt spreader drivers. Maneuverability tests will be conducted in the evaluation. Some spinner assemblies may be too high relative to the bottom of the TMA. This means that as salt is thrown off the spinner to the rear of the truck, it would hit the TMA and hence disrupt the spreader pattern. Remedying this situation may require modification to the spinner assembly, such as lowering it, and increasing spinner speed or the size of the spinner disk.

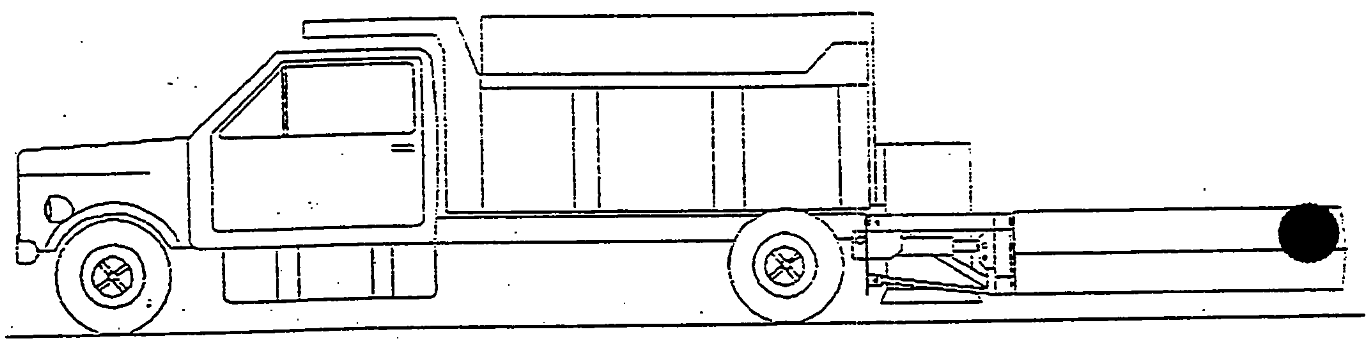


Figure E-6 - Salt Spreader/TMA Interface Structure

Given this however, the Salt Spreader/TMA Interface Structure has the potential of eliminating many of the injuries to workers and motorists when motorists hit the back of a salt spreader.

Testing of the Salt Spreader/TMA Interface Structure should include a 5400-lb vehicle impacting head-on at 45 mph. Two vibration tests should be performed to determine the structure's ability to withstand the vibration associated with travelling. Each test should have a frequency of 5-8 HZ, and excursion on 0-.60 $\pm$ 0.05-in, and 40 hours for each test. The same article should be used for both tests. The article should be essentially undamaged after the vibration tests.

Portable Crash Cushion

Background & Device

The Portable Crash Cushion is a system of equipment that will carry a complete sand barrel crash cushion array on a moveable platform. The trailer is used to quickly move the crash cushion into a closed traffic lane upstream of a maintenance operation. The trailer is designed to allow two cushion arrays to be placed alongside of each other in order to completely block off the traffic lane.

The pallet, which serves as the platform for the cushion barrels, and the lifting rig form the trailer system. The trailer with the pallet in the up position, is shown in Figure E-7. The pallet is designed strong enough to carry the weight of the cushion barrels from three lifting points. The W beams along the sides of the pallet serve as guide rails for the two lift rollers. The lifting rig is a rigid, triangulated steel structure. Three hydraulic units are used to raise and lower the loaded pallet. Once the pallet is in the raised position, lock pins are inserted to prevent the pallet from accidental lowing in case hydraulic pressure is lost. This also serves to make the pallet and the lifting rig a more rigid assembly.

The suspension for the lifting rig is composed of longitudinal swing arms that carry spindles for the four wheels. These arms are pinned to the vertical support legs of the lifting rig. "Coil Over Shocks" will handle the spring/damper suspension requirements. The tires are 215/75R17.5 12 ply tires which are rated to 4410 lbs each at 125 psi. Inside each wheel will be pneumatically actuated brakes. The brake pressure will be supplied by the tow truck's pneumatic system.

The vertical support legs will contain the lifting strut and the hydraulic units (one hydraulic unit per side). The lifting struts will have guide/lift roller assemblies that will facilitate the use of the lifting rig. The lifting struts will have guide/lift roller assemblies that will ride along the channels in the W beams. These guide/lift roller assemblies serve two functions. They facilitate the positioning of the trailer to the pallet and they provide the lifting points for the pallet once they are up against the stops in the W beams.

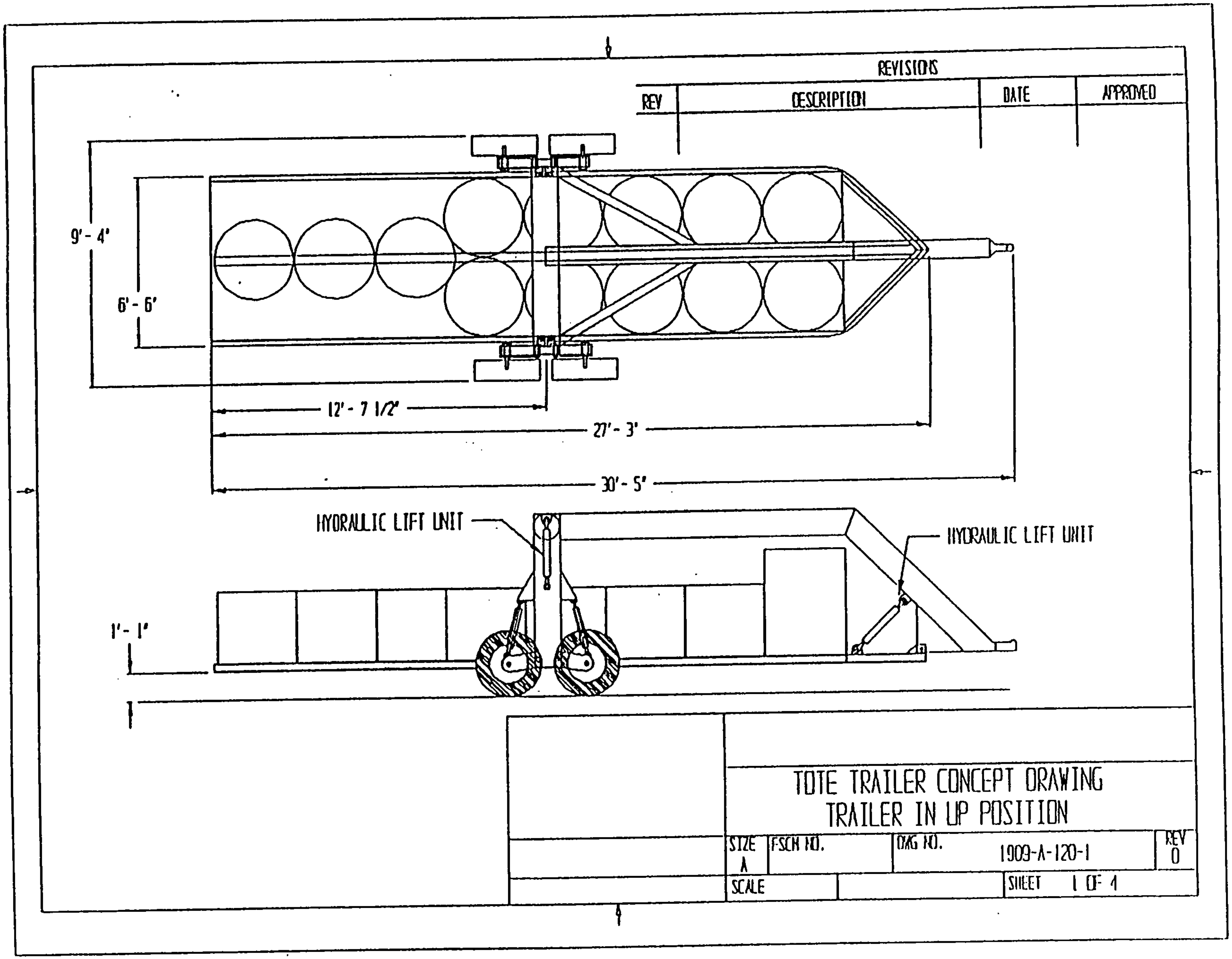


Figure E-7 - Portable Crash Cushion

The forward hydraulic unit serves to lift the front of the pallet and to cinch the guide rollers against stops in the W beams. The position of the stops in the W beams shall be located so that the vertical load on the tow hitch will be less than 3500 lbs (the load is balanced on the lifting points to induce only 3500 lbs of force on the hitch). All three hydraulic units can be ENERPAC double-acting 14.5 inc. stroke units (part# RR-3014, approx. $640 each). The pump requirements for these cylinders would be met by an ENERPAC EGM-445 gas powered hydraulic pump (approx. $1769). This pump would be mounted on the trailer near the forward hydraulic cylinder.

The pallet would be of a composite construction strong enough to withstand the cantilevered load of the barrels that are behind the lifting points. A construction using three W4 X 13 beams sandwiched between two 3/16 inch plates is sufficiently strong.

The towing hitch assembly would use a pintle hook rated to 10.0 tons attached to a 2 1/2 inch steel shank bar (ACAR pat #567). This shank bar would mount into the tow truck receiver. The trailer would have a lunette eye welded to the trailer frame with a rating of 10 tons and a maximum vertical load capacity of 2 tons (ACAR part #LE-2). When the Tote-trailer is not hitched to the tow vehicle it will be supported by a removable jack with a 5000 lb load rating (Fulton part #515TH20).

By using as many off-the-shelf components as possible the Portable Crash Cushion system can probably be built for $20,000 or less given the simplicity of the system (this does not include design costs).

Installation

To lift a loaded pallet

A loaded pallet would be lifted using the following procedure. A truck would back the lifting rig up against the pallet. Due to the difficulty in precisely backing up a long trailer the driver would only have to assure that the vertical support legs of the lifting rig fall to either side of the centerline of the lifting rig fall to either side of the center line of the pallet. Rub bars and the lift/guide rollers would align the lifting rig as the rig was backed up.

An assistant would notify the driver when the guide/lift rollers were in position against the roller stops in the C channels. The forward hydraulic cylinder is then attached to the pallet. Then the pump is started and the hydraulic cylinders are retracted until the pallet is completely lifted. Three lock pins are inserted to prevent the pallet from accidentally lowering during transport. the pallet can now be driven to a new position. As the barrels are not anchored to the pallet, the speed limit for the system should be 45 mi/h.

Removable restraint railing can be designed to be inserted into the pallet for transport over longer distances to prevent the barrel cushions from shifting off the pallet during pronounced braking.

To unload a loaded pallet

To unload the pallet, the driver positions the pallet in the desired position and sets the vehicle brakes. The three lock pins are removed from the lifting rig and the hydraulic control valve is slowly opened to lower the pallet. Once the pallet is completely lowered the driver can simply drive the lifting rig straight away from the pallet.

Maintenance

The Portable Crash Cushions System should have only modest maintenance requirements. The guide/lift roller should be lubricated periodically along the W beams. The hydraulic pump system should require maintenance only as recommended by the manufacturer. The structural elements of the lifting rig and pallet should be painted as required to preclude excessive corrosion.

Removal

See installation section.

Appendix F

Warning Device Designs

Introduction

In Area 2, Warning Device Designs, a large number of concepts were proposed. A total of nine concepts were presented in these proposals. These nine concepts were broken down into three basic categories of devices that were selected for further development. One category of detection devices involves ultrasound, the second makes use of infrared technology transmitters and receivers and the third utilizes pneumatic tubes for detection of errant vehicles. All of these detection devices except the Infrared Queue Length Detector are intended to detect errant vehicles posing hazards to workers in exposed work zones. The Infrared Queue Length Detector alerts workers when long queues are forming on the approach to a work area. The Portable Protective Warning System is a combination worker warning and traffic control device.

In the Project H-108 plan, seven tasks were presented for the development of these devices into working prototypes. Tasks 1 thru 3 were completed in the Project H-108 effort. The remaining four tasks are to be completed in the Project H-109 effort. Table F-1 describes these tasks. In Task 1, Design Plan Preparations, all the relevant proposals were investigated and those that held the most promise were selected for further development. In Task 2, Design Prototypes, two of these were selected and investigated in great detail with specific design modifications determined and planned for fabrication.

Table F-1

Tasks for Warning Device Prototypes

Task 1 - Design Plan Preparations	Contact proposers, do literature search, contact manufactures to determine capabilities and limits of proposed sensor concepts. Select optimum sensor(s) for application. Eliminate impractical designs.
Task 2 - Design Prototypes (2 only)	Determine needs for support circuitry and required interfacing to implement concept. Select components to be used as needed.
Task 3 - Fabricate Benchtop Prototypes	Fabricate custom components, if required Assemble bench breadboard and do simple tests. Debug as needed to do obtain proper operation. May perform simple field tests to check operation to modify circuits correctly.
Task 4 - Build Field Prototypes	Build field ready unit per design as modified for Benchtop prototype.
Task 5 - Test Field Prototype	Test first in test tracks then in actual maintenance work zones for correct operation, determine detection limits, document detection problems.
Task 6 - Finalize Design	Determine needs if different as tested in field prototype. Optimize for best manufacturing potential. Test optimize unit.
Task 7 - Implementation Package	Develop final design specs, schematics and mechanical drawings, write manuals for operation, maintenance, etc.

Infrared and Ultrasonic detectors were the two selected for this Task 2 effort and design plans were made. A third detector design, the Pressurized Pneumatic Tube, was also selected but was not addressed in this effort because of its simplicity. It could be taken right to the field prototyping without benchtop testing. The final H-108 Task 3 consisted of the benchtop prototyping and lab testing of the two selected detectors, Infrared and Ultrasonic. The effort in H-108 basically evaluated systems for further development. The system integration required for the proposed concepts required no major development effort to function as full systems but the detector technologies proposed, were not as simple. The effort on H-108 was, as a result, confined to detector technology development.

The descriptions of the efforts accomplished in this Project H-108 (Tasks 1 thru 3) effort are presented in the following sections. Although three concepts were chosen for development, only two were selected to be evaluated here. The third concept was investigated but not developed. The following section will present the development effort on these two concepts and the findings of the evaluation of the third concept. The two concepts chosen for further development are the infrared and ultrasonic. Both retroreflective and diffuse reflective infrared devices were explored and the use of Ultrasound detectors were selected as the most appropriate transmitter receiver device.

Ultrasonic Detection Alarm

The use of motion or proximity detection to identify errant vehicles endangering workers in work zones was raised in proposal 843 (Life Saver) and was selected for further evaluation and development. A large number of such detectors were evaluated and ultrasonic was selected as the most appropriate to serve as the basis for further development of this proposal. This proposal presents a complete system. The system proposed uses existing technology requiring only minor efforts to interface chosen warning sirens, etc. with the selected detector technology. The use of the ultrasonic devices as a detector is for this and required selecting an appropriate detector system and evaluating it in detail. The results of the evaluations as well as the modifications required as identified in the evaluations will be presented in this section.

The following sections will present details regarding the selection of the ultrasonic sensor, a general description of the sensor, detailed presentations of the operation of the sensor, modifications proposed to optimize the unit for the applications described in the proposals and the methods by which this technology will be tested for compliance with the needs of the field operations. Figure F-1 illustrates the proposed use of this technology.

A large number of ultrasonic sensors exist which are tailored to specific applications. It was quickly determined that the technology is sufficiently complex that a full design effort to develop a custom ultrasonic system specifically for these applications is not very practical. It was decided to locate an existing ultrasonic system which will fit our specifications closely enough to allow minor modifications to fully adapt the unit to serve the proposed effort. The Polaroid Ultrasonic Ranging System was selected as the most appropriate. It was a simple, low cost, mass produced unit typically used in their cameras and it came with extensive documentation and support. The range

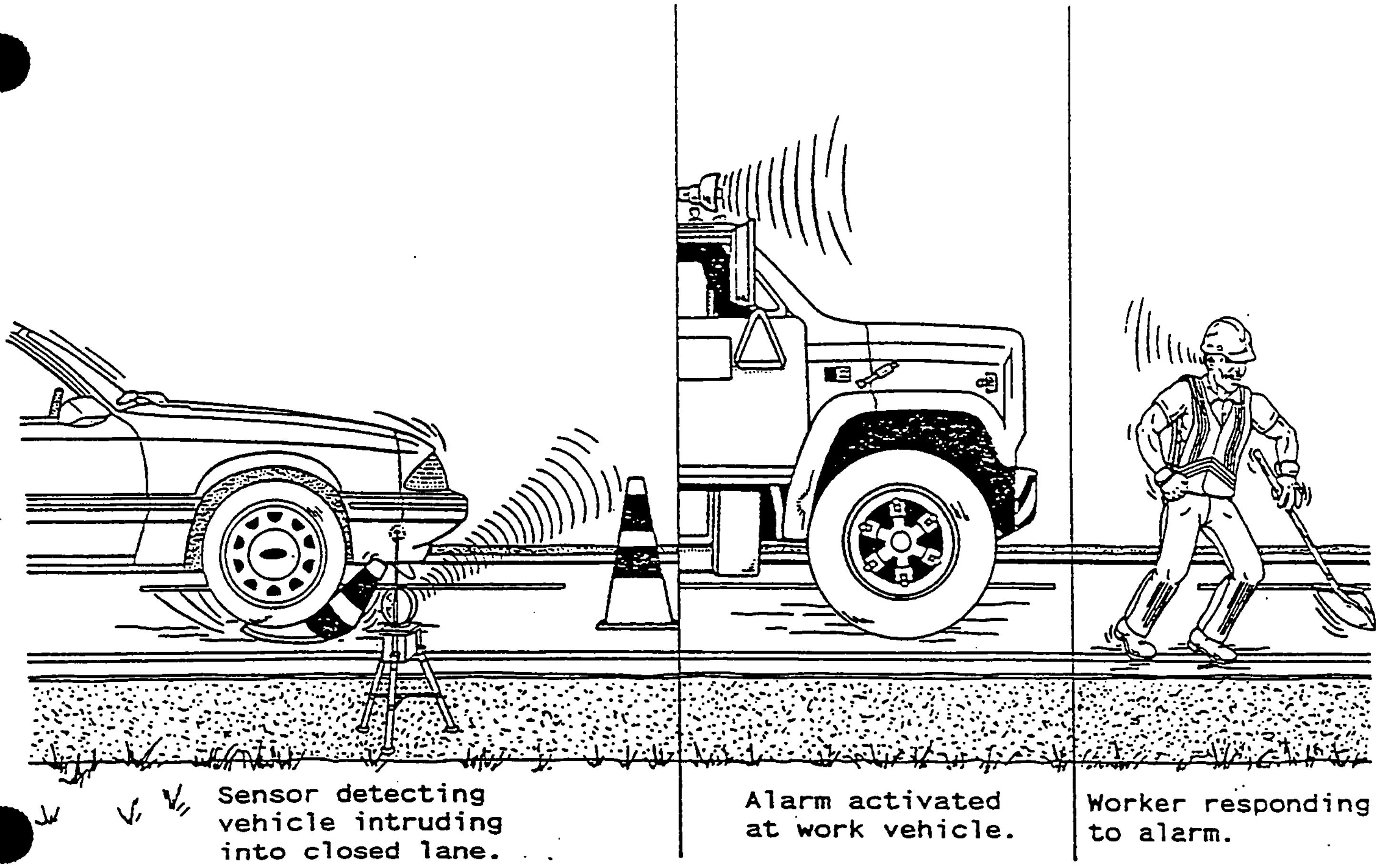


Figure F-1 - Ultrasonic Detection Alarm

was limited by design since ranges over 35 feet are not needed for camera focus (>35 ft = infinity). This helps in reducing false alarms for the proposed application in that the device in incapable of seeing vehicles in other lanes or on other roads or locations. Furthermore, the range at which the vehicle in the beam was detected could be determined precisely so that simple logic could be employed to virtually select the range of detection used to trigger an alarm. The adaptability of both the sensor and its detector technology was very desireable so one of these units was purchased and detailed evaluation of the technology was conducted.

The unit consists of three basic components, an acoustic transducer, a ranging circuit board and an interface board. These three components make up the system that was to be evaluated. A field duration 50 khz pulse train is applied to the transducer, used as a transmitter. This generates the ultrasonic signal. Immediately after this signal burst, the transducer is switched to a receiver and monitored for incoming signals. While the receiver is waiting to detect a signal, the transmitted signal is continuously getting weaker and the receiver sensitivity is increasing with time so that the signal can be recognized. If the signal arrives before the time period corresponding to 35 ft is reached, a detection signal is generated. Once the time period corresponding to about 35 ft is reached with or without a signal detection, the transducer switches to transmit mode and the cycle begins again. If the signal from the first transmission returns after the second transmission is issued, the gain applied to the incoming signal will not be enough for the incoming signal to be read. This reduces the possibility of a false alarm from a distance reflected signal. No false signals are possible due to the low signal strength of far away echos and the low sensitivity of the receiver. These functions are all performed by the ranging circuit board. The interface board uses all of the logic signals and uses the time to detection to tell how far away the target is in the ultrasonic beam.

The transducer is a low cost mass produced (readily available) ultrasonic transmitter/receiver used to both emit and detect the ultrasonic signals. It is a very simple device made up of an insulated foil stretched over a rigid grooved plate. This forms a capacitor which exerts electrostatic forces on the foil when exposed to pulses of energy. Once excited by the energy to emit ultrasonic pulses in the transmitter mode, the transducer is then used as a sensitive electrostatic receiver to listen for the reflected signals. The ranging circuit board provides the pulses and reads the signal from the transducer.

The ranging circuit board has three major circuits, a digital circuit, an analog circuit and a power circuit. The digital circuit controls all of the timing functions and is the source of the 50 khz clock signal. The power circuit takes the low DC voltage used to power the system and steps up the voltage and current to provide the power pulses to the transducer. The analog circuit monitors the incoming signal and adjusts the automatic gain control as time increases. It generates the detection signal if the ultrasonic echo is

detected within the required time frame. All of the timing, operation and detection signals required for the operation of the ultrasound ranging system are provided by this ranging circuit board.

The interface board is required to read the timing and detection signals from the ranging board to create a method for using this data. Many techniques can be employed to read, interpret and present these signals to act as a range specific detection system. The basic Polaroid system had a standard interface board available and it was also purchased. It uses the timing signals from the ranging board to mark time by counting a continuous pulse train between the time the transducer is converted to a receiver until either a detection signal stops the count or the time is exceeded and the timing is halted. This count data is proportional to the distance the unit is from the detector emitting the pulse train. This data from the interface board can be latched and presented to a digital to analog converter to provide a voltage output. This voltage can be used in voltage comparator circuits with the output from these circuits used in logic circuits to specifically tell if the detected vehicle is in the zone of interest. If it is, an alarm can be sounded to alert the workers to vacate the endangered work area. This interface was developed in H-108 Task 3 in Table F-1 as specified in the reference material provided with the ultrasound unit. The circuit functions adequately as fabricated but improper information in the reference material caused the interface circuit operates poorly. Although this kept the unit from being tested in H-108 Task 3, a great deal of useful design information was gathered from this effort. Minor redesign of the circuits will clear up this problem so that the ultrasonic unit can be field tested in H-109.

During the initial evaluation of the existing off the shelf Polaroid units, two areas for improving the system were identified. One of these dealt with the overall time interval for detection cycles. It may be possible for high speed small vehicles like motorcycles to pass by undetected in between ultrasound pulses. Although not likely to occur, it was felt that this was addressable with circuit modifications to the system without a total redesign. The clock circuit frequency was doubled to shorten the cycle time to catch these fast small vehicles. Once this was accomplished another improvement was deemed practical.

At the same time the timing cycle is shortened the transmission frequency of 50 khz was doubled to 100 khz to shorten the range and to boost the rate at which the receiver gain is increased to read the less intense incoming signals. These changes make the unit more sensitive to the work zone area of concern and to further reduce the possibility of false alarms. These developments were initiated in Task 3. The problem with the poor interface circuit, previously described, kept the unit from being used in these efforts. Preliminary designs were made, parts were ordered and the fabrication was began but not finished. Again, these problems are only minor in nature and will not hinder the field testing of the ultrasound unit in H-109 Tasks.

The circuit on the ranging board was also selected for rebuilding to remove several proprietary components used in the Polaroid design. All of these efforts were conducted in this phase of the Project H-108 effort in Area 2. A number of simple benchtop tests were conducted in this Project H-108 effort to determine the nature of these problems and assess the results of the modifications. Much more substantial tests will need to be conducted in the Project H-109 effort to more fully assess the impacts of these modifications.

The tests to be accomplished in Project H-109 efforts would be required to assess the characteristics of the design modifications on the existing Polaroid circuits. A number of stationary target tests would be conducted to determine how the range has been affected. The output of the new circuits would be monitored to collect data comparing the output signal with the detected object distance. This determines the useful range of the new circuits and the data can also be used to develop a voltage distance relationship which will be used to set alarm points for use of this detector in a full system. Another series of tests would be conducted to determine if the sensitivity of the modified circuits have been affected. A smaller object (ie motorcycle or bicycle) will pass in front of a larger object (ie car or truck) to be sure that the object detected is the smaller of the two. It is important to note that smaller objects have smaller reflected signals which will be below the detection limits at some distance from the detector. The modifications were designed to avoid this problem and these tests are required to confirm this. High speed moving target tests will be conducted to assure that fast moving small targets can be easily detected. One of the modifications was made to assure this and this test should adequately demonstrate this. Both designs use ultrasonic signals in the low Khz range (50-100) and some types of noise can emit signals in these ranges also. The detector is looking for a signal pulse in the right frequency range so this should not be a typical problem. Tests will be conducted to determine if there is a possibility of interference. Bench top tests using amplified signals from signal generators will be used to simulate noise with the desired characteristics. If the unit is found to be fooled by these noises then the natural occurrence of this noise will be determined so that the sensor can be positioned away from potential noise sources. For example, air blasts from compressors can create ultrasonic noises.

In summary, the ultrasound unit selected is typically not susceptible to false alarms. In addition, ranges can be specifically set to send an alarm only for vehicles within a certain range and ignore all others. The unit is low enough in cost that multiple units can be utilized to offer redundancy for fail safe operation. The unit is battery operated and it is not overly sensitive to battery voltage. It is light enough not to pose a crash hazard. The sensor is also impervious to the environment although range can be reduced under certain conditions such as heavy rains or extreme cold but no highway maintenance activities occur under these conditions either. The unit can also be located well in advance of the work area and alarm indications can be sent to remote locations via radio transmitter or hard wired cable. The unit is relatively simple to set up, operate and test in the field environment.

Infrared Intrusion Alarm

The use of intrusion alarms was proposed in two proposals selected for continued development. Proposal number 506 presents a work area intrusion alarm based on infrared technology. The second proposal, number 692, describes an infrared vehicle detector. Both of these proposals utilize various forms of infrared technologies for detection of errant vehicles which could jeopardize the lives of workers if they are not adequately warned in advance by an alarm sounded by early detection of the errant vehicle. Infrared has been used in a wide variety of applications for detection of intrusion although mostly for use indoors in relatively clean environments. Recent development in the use of infrared for detection have advanced its use in dirty environments such as dusty outdoor work zones. It was felt that infrared merited further investigation and was therefore selected for further evaluation and testing for the proposed applications.

The following sections will present details regarding the selection of the infrared detector, a general description of the detector, a presentation of the infrared detector operation, and the method by which this technology is evaluated.

A significant number of infrared detectors currently exist. Many are not applicable for the proposed applications. The advances in infrared applications are not widespread as of now and appropriate detectors were limited in availability. Several manufactures of the more advanced infrared detectors were located and one was ordered. Two forms of useable infrared devices were available and both were ordered for evaluation. Both of these units consisted of a fairly standard infrared emitter and detector. It is the usage of these emitter/detector pairs that make these units unique. The infrared emission is pulsed and the detector is set up to recognize only infrared signals of a certain frequency. In this manner, the device is relatively immune to external influences such as light and dust that affect the signal strength. One sensor used retroreflective type design while the other utilized diffuse reflection. Both of these forms of infrared detection can be utilized for the intended applications.

The basic emitter is pulsed and the pulse rate is variable (with minor design mods) which would allow multiple units to reside side by side and not interfere with one another. The pulsed beam is sent out and if it strikes an object, the signal will be reflected back to the device. The reflected signal is received by the detector and passed through a filter which allows only one narrow band width frequency to pass. If the received signal is at the correct frequency the unit will signal that it was received. If the signal if not the right frequency, the received signal will be blocked by the filter and the unit will not respond.

The retroreflective type infrared device looks for this kind of signal to be present continuously. For this application, a fixed reflector and the infrared unit are set up opposite each other across the area to be protected. The typical application of the Infrared Detector Alarm is shown in Figure F-2. The alignment is reasonably critical but it is not difficult to accomplish. A reflector pavement marker can be used to reflect the signal and once the unit is set up, any breaking of this beam, the loss of the reflected signal, will trigger an alarm. This type of unit is very simple and requires very little technical development. The use of the pulsed beam keeps reflections from other infrared sources, such as the sun, from masking or otherwise affecting the units ability to detect errant vehicles.

The second type of infrared detector uses a diffuse reflection. This unit is much easier to set up and use. The errant vehicle is basically used as the reflector. The received signal can be very weak because the diffuse reflection is just that, very diffuse or scattered. Extreme amplification is used to detect such a small signal. The pulsed signal is sent out and if an object is present

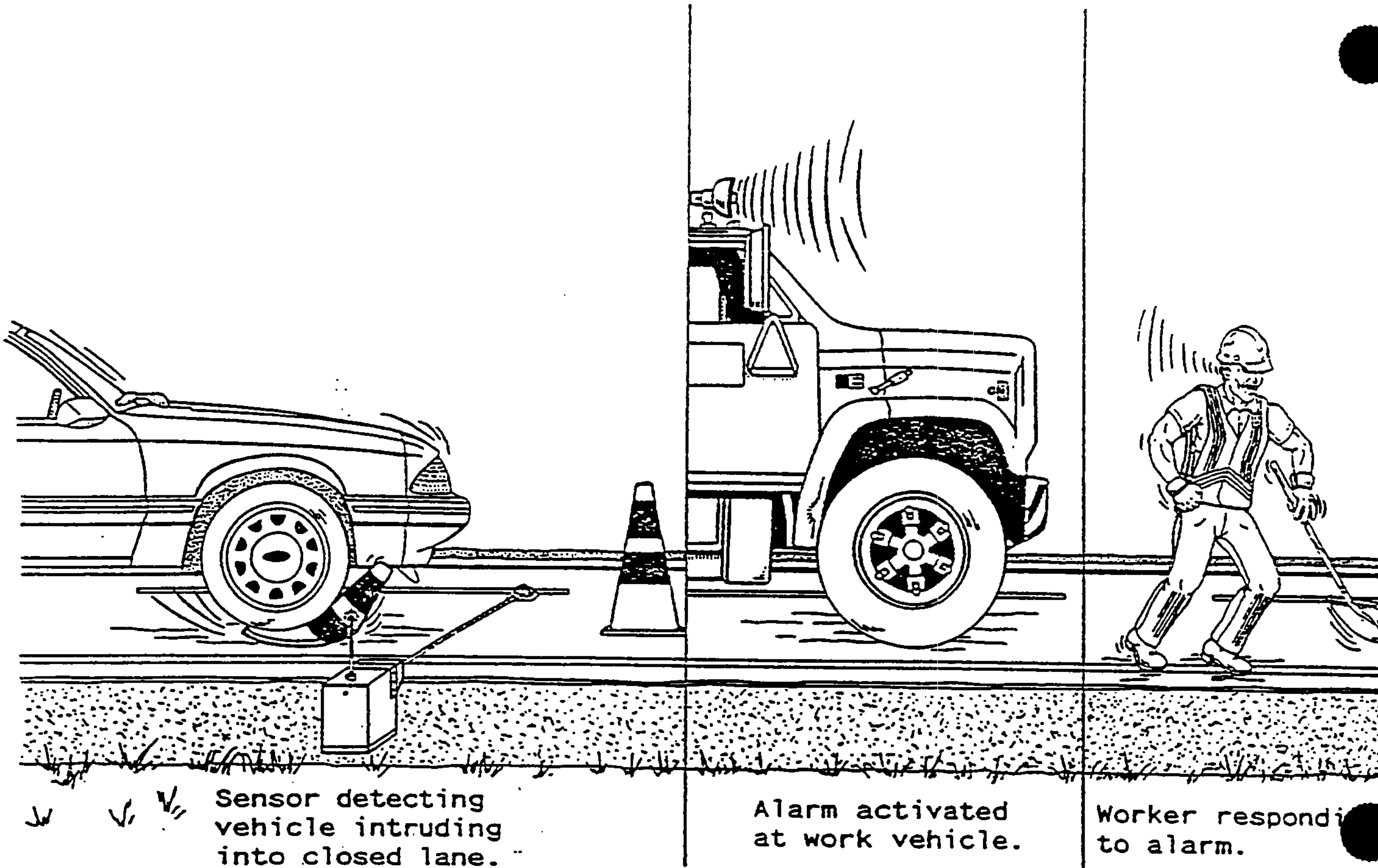


Figure F-2 - Unfrared Intrusion Alarm

in the beam it will be reflected back in some manner. As long as no signal is received or a steady signal (ie sunlight) is received, no alarm is indicated. If the right frequency signal is received, amplified and therefore detected, an alarm will be sounded. No modifications are required to use this technology directly, but, like the retroreflective unit described above, the correct usage must be established and testing conducted to determine the reliability of this type of device.

Testing conducted in the H-108 phase of this activity was used to determine an number of operating parameters and limits associated with the diffuse reflection type units. Since cars and trucks come in a wide variety of sizes and shapes and have different colors and qualities of paints or other reflective surfaces, testing was conducted to determine what effects the reflective surfaces will have on the return signal strength (detectability). In general, almost all vehicles, clean or dirty, old or new, or any color at all could be detected with little or no trouble. It was found to be fairly important to keep the emitted beam as perpendicular as possible to the vehicle path to maximize the return signal for easy detection. The testing also showed that a strongly reflective object could easily be detected, in much the same manner that a retroreflective device would operate. This means that a means of limiting the range of the unit must be used. The signal strength is not an option to reduce the range because the high output is required to get a reasonably strong reflection from the passing object. The gain of the amplifier for the received signal is also not appropriate for much the same reason. A small barrier must be set up to block the transmitted signal at the desired range. This makes the unit similar in set up to the retroreflective type unit. Because of these problems, the diffuse infrared unit can not be made as reliable as the retroreflector unit. As a result, the diffuse infrared unit must be dropped from consideration as being impractical.

In summary, generic infrared has problems that make the use of infrared difficult in all but the cleanest and most controlled environments. The newer infrared devices can incorporate the use of infrared beam pulsing to make the signal detectable from background infrared sources such as sunlight. It also allows the use of infrared in dirty dusty environment because the receiver gain can be boosted such that very small signals can be easily detected in high infrared ambient backgrounds because of the unique nature of the pulsed beam. The retroreflective type infrared detector is easy to use, requires some effort to align but is not difficult to install. The diffuse reflective unit is much easier to install but can get false signals if strongly reflective signals are received even from long distances and must be dropped from further consideration. Further testing of this nature will be required in the H-109 phase of this contract to more completely evaluate the correct strategies for implementing the retroreflection infrared unit to assure maximum reliability and minimum false detections.

Pressurized Pneumatic Tube

The use of pneumatic tubes to indicate the passage of a vehicle, either for counting or for warning, is not new technology. What is new is the implementation of this old technology. Three proposals, Proposal 270 - Buffer Zone Alert System, Proposal 108 -Early Warning Device, and Proposal 739 - The Lookout, all propose the use of this novel pneumatic tube concept. These proposals present the potential usage of a pressurized pneumatic tube. This allows the tube to sense both a vehicle passage to sound an alarm and to sense the failure of the tube to alert the workers to a loss of protection.

This concept is extremely simple and is not difficult to set up. A pneumatic tube is placed under low pressure by sealing the ends, installing a simple fill stem (like a fill stem on a bicycle tube, and pressurizing to a few inches of water pressure. The tube pressure needs to be high enough to sense it using low cost pressure sensors yet low enough that seepage of the air from the tube is easily stopped and hopefully low enough that standard pneumatic air tubing can be used. A pressure transducer with both low and high pressure set points will be used to determine alarm conditions.

The operation is simple. Check the pressure and place the tube where desired. If a vehicle drives over the tube, the pressure is momentarily increased and detected by the pressure sensor. An alarm is sounded to warn the workers see Figure F-3. In this manner, the pressurized pneumatic tube is not different from the standard pneumatic tubes. If, however, the hose is damaged or the pressurized air leaks out of the tube, the tube is worthless for detecting errant vehicles. The pressure sensor will detect this drop in pressure and a different alarm will be sounded to call for a tube replacement. This essentially makes the tube fault tolerant.

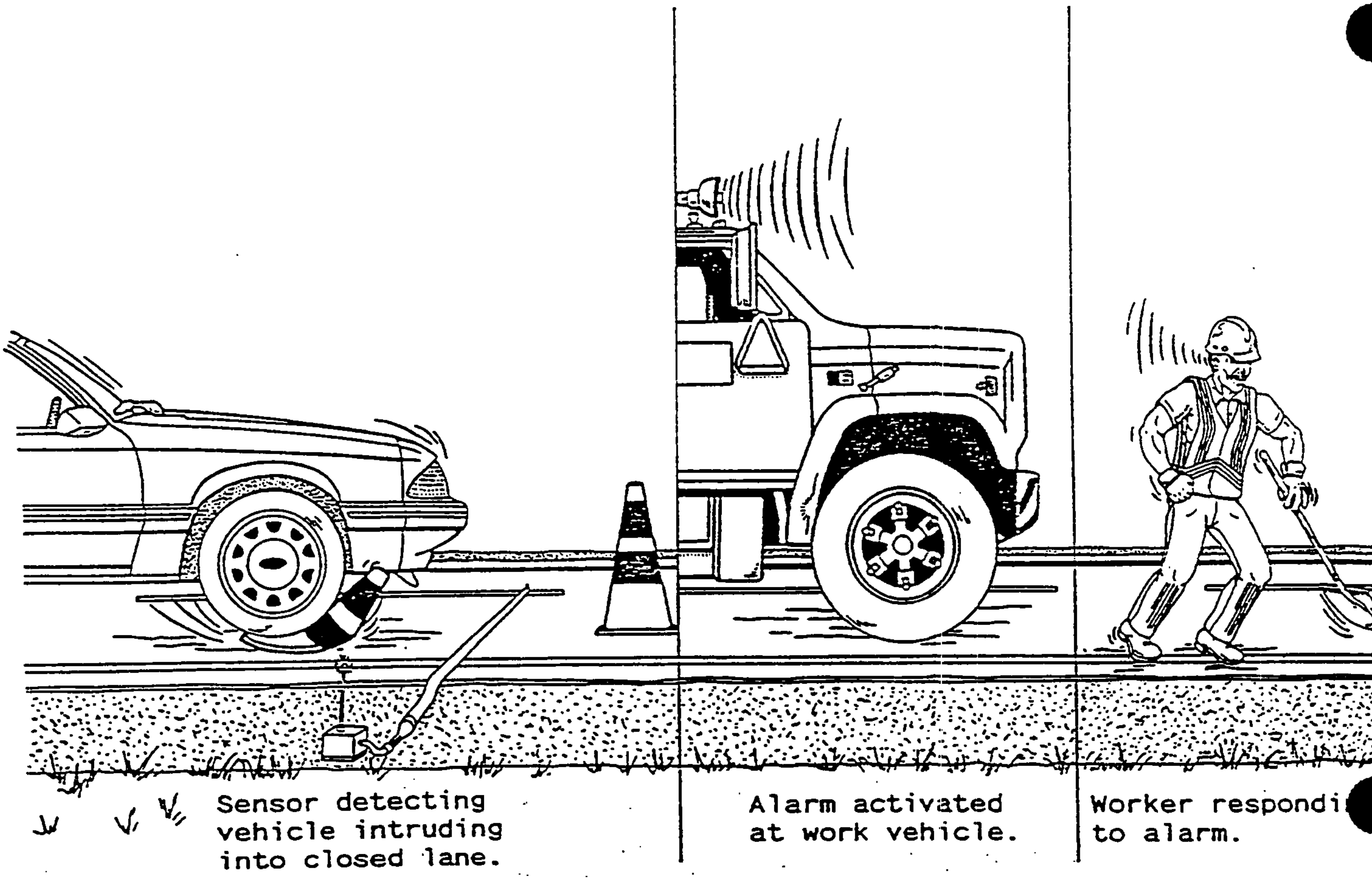


Figure F-3 - Pressurized Pneumatic Tube Alarm

This detection concept was selected for further development but required limited development other than optimizing the system for reliability. Because of this, no effort was planned for the Project H-108 effort. Full development and testing of this device is planned for Project H-109.

Queue-Length Detector

In proposal Number 912, the Infrared Que-Length Detector consists of two infrared detectors placed 12 feet apart, two miles in advance of the work zone. An informational buzzer, and an omni-directional flashing light are used with the detectors. The purpose of the system is to inform workers of a back up of vehicles in advance of the work zone. This enables the workers to adjust advance warning signs, or a variable sign message, to improve drivers' understanding of the work zone. Upon activation, the output from the infrared detectors is transmitted to the work zone receiver, which in turn activates the buzzer and flashing light, informing the workers of the development of a traffic queue.

Infrared units were examined but the only type with an effective range needed were retroreflective. Retroreflective units need precise setup and this would have been very difficult in this application. Ultrasound detection was investigated and the Polaroid Environmental Sensor was chosen as acceptable for these purposes.

The application of the queue length detector is shown in Figure F-4. The polaroid environmental sensor and a tripod setup will be used.

The poloroid environmental sensor will sense the proximity of an object up to a preset range. This device will detect a traffic backup and alert the road crew so that they can take actions to alleviate the traffic jam. Two sensory units will be placed 12 feet apart in advance of the construction taper. The basic component operation is the same as that of the ultrasonic errant vehicle detector.

Portable Protective Warning System

Human Factors Evaluation

This device is composed of various elements, which are generally not novel in themselves. It is the combination of these elements into a single, self-contained portable system that is the major innovation. The functional aspects of the system include:

* Impact attenuator
* Arrow board
* Traffic activated, radar based speed control message board
* Speed alarm (to alert driver and work crew)
* Encroachment alarm for the driver
* Encroachment alarm for the work crew

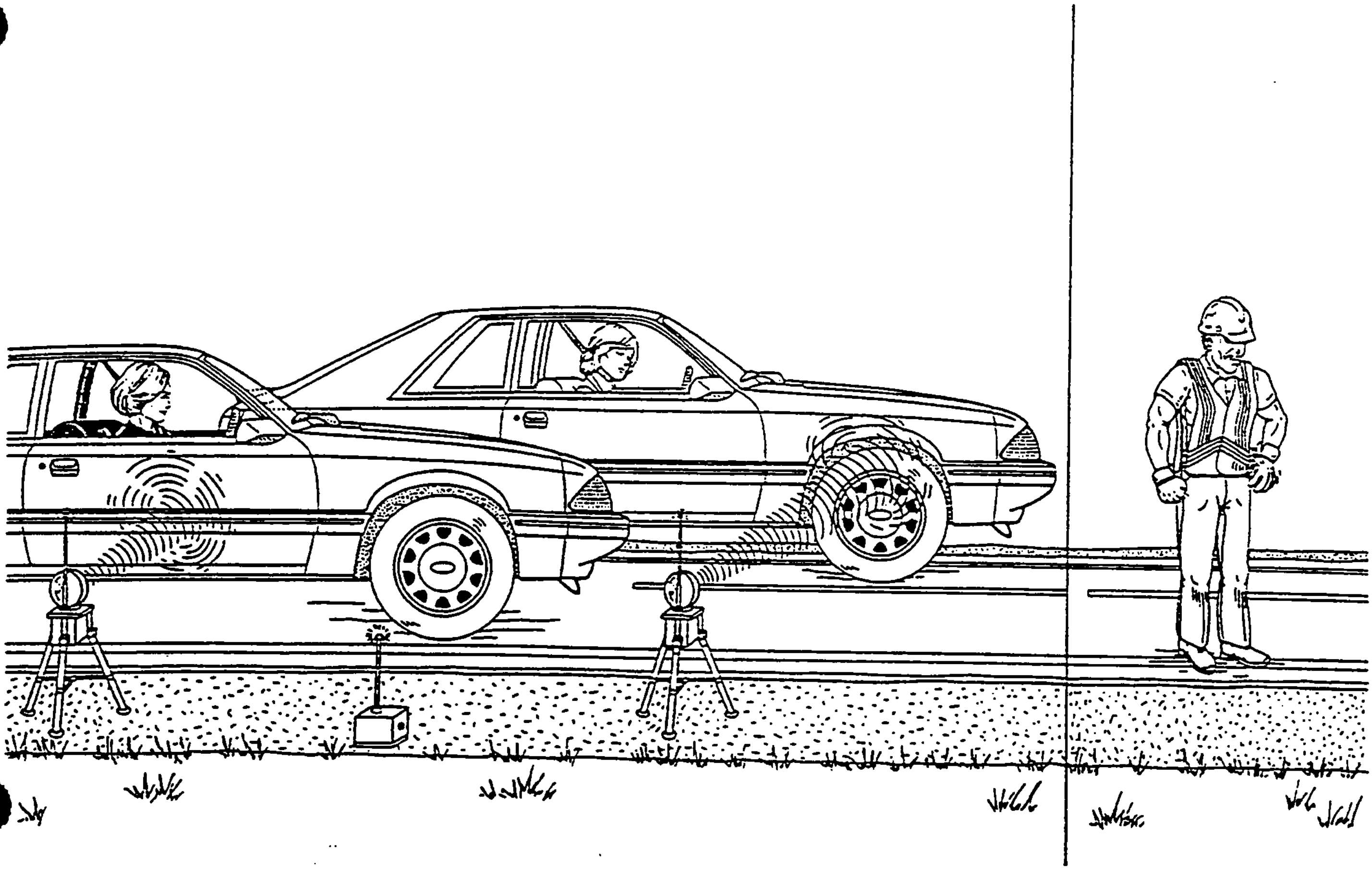


Figure F-4 - Queue-Length Detector

The first two of these features require little comment from a human factors perspective. The impact attenuator should be well delineated by standard object markings, but otherwise has no human factors consideration. The arrow board is a common component of work zone delineation system with well understood benefits, and so does not require discussion.

Other issues are discussed below under the general headings of speed control, speed alarm, encroachment alarm, and application.

Speed Control

Traffic-activated speed control TCD's have some promise for reducing traffic speeds if properly used. However, they may not be fully effective if used in the manner described in the submission. Key points are:

1. Displaying both the speed limit and the driver's speed on the same panel will be confusing, and the numeric display itself will not strongly attract attention. When a speeding vehicle is detected, it would be more effective to activate a message such as "TOO FAST", "REDUCE SPEED", or "SLOW DOWN", and/or activate flashers.

2. The speed warning needs to be perceptually tied to the hazard of the work zone. The results of studies of traffic-activated speed controls have been mixed in the literature; however, some of the clearer successes were obtained when the speed feedback was tied to an explicit hazard (sharp curve, exit ramp).

In general, compliance with signs is improved when the context supports the message. Therefore the speed warning should not appear as a "stand alone" device which the driver may fail to recognize as part of the work zone warning system. Other TCD's, either integrated into the proposed device or used with it, must make it clear that there is an immediate risk ahead if the driver does not slow down.

3. The siren, which sounds if a speeder is detected, is probably not a good idea. There is already a lot of speed variance and potential for traffic conflict in the work zone area. The work zone safety devices themselves should not encourage erratic maneuvers, sudden braking, or startle reactions. Given the required intensity of the alarm, these sorts of reactions are predictable (Research has indicated that signal intensities of 87 dB at the vehicle are required to be reliably detected, and this research did not even include extreme acoustic conditions, such as loud sound systems, which would certainly occur. If the alarm is designed for these "worst case" conditions, it may be exceptionally loud under other conditions, e.g. passenger car with radio off and window open). Furthermore, since the source of the siren may be unclear, the driver may engage in search for the source at the very time he most needs to be attending to path cues and other vehicles.

4. Incorporating radar into the system, so that it can set off in-vehicle radar detectors in approaching traffic, may be useful if it does not induce sudden braking. Of course, drivers will eventually learn that the radar is not manned

if it is part of this device, but that may not be obvious at the time the radar detector goes off. There may be some questions of legality and/or public acceptance.

5. It is not clear from the literature whether speed variance will be increased or decreased by the speed control message, and the outcome may depend on what speed levels trigger the device alarm. Speed variance should be closely monitored in any field evaluation.

6. If this device were routinely used, drivers would learn that the speed measurement was not tied to enforcement (unless special efforts in the enforcement area were undertaken in conjunction with device use). Therefore some of the initial effectiveness of the device might be taken as transitory. However, a good response might still be retained if (a) only truly significant speeding is targeted, rather than anything in excess of the posted speed (this will reduce the likelihood of the message being perceived as unreasonable or as a false alarm); (b) the visual speed message has good conspicuity so that it continues to attract drivers' attention, even when it is no longer novel or intentionally attended to; (c) the validity of the hazard warning is maintained, both through the reliable occurrence of nearby road work and through the perceptually obvious relationship to the work zone as discussed under point 2 above.

Speed Alarm

The speed alarm, triggered when a driver exceeds some target speed, is intended to alert both the inattentive motorist and the work crew ahead. We have already discussed the problems of reliable driver detection of acoustic signals and the possibility of undesirable responses (startle, braking, searching).

For the work crew, the speed alarm will be of limited effectiveness. Problems of acoustic detection in the potentially noisy environment exist here too. It is not clear if the alarm (for the driver) presumably mounted at or near the radar unit is the only one for the speed warning, or if additional units will be located in the work zone. If only located at the radar unit, sound levels several hundred feet away may not be adequate. If additional units are located in the work area, more equipment, cable, and effort are required to set up the system.

Probably the biggest concern with the speed alarm for the work crew is the deleterious effects of false alarms. High false alarm rates are recognized as a major problem in many different kinds of warning system: they lead to ignoring of the signal, slow response times, annoyance and poor acceptance, work disruption, and intentional defeat (turning off, over- riding, breaking, or otherwise disabling) of the warning mechanism. One can assume that most speeding vehicles actually will not present a threat to workers by the time they reach the work area, and so the warning will essentially be a false alarm. If the speed alarm is acoustically distinct from the encroachment alarm (as implied in the submission), the speed alarm will rapidly lose effectiveness as a warning. If it is made identical to the encroachment alarm signal, the response to actual encroachments may be degraded.

Encroachment Alarm

The submission includes two means of detecting vehicle intrusion into the work zone: an electrical contact type control line laid alongside the cone taper, and/or a motion detector. In either case, intruding vehicles would trigger two alarms: a "irritating yelp" directed at the driver, and "foghorn type sound" directed at the crew.

Since both the driver and crew alarms would always sound together (being triggered by the same detector), the logic of providing multiple signals is not clear, and only adds to the complexity (physical and perceptual) of the system. The submitter apparently feels that there may be significantly better responses on the part of drivers vs. workers to different selections for acoustic parameters.

Probably the key issue for this or any other encroachment warning device is defining encroachment in such a way as to provide enough reaction time for the work crew yet minimize the occurrence of alarms that are not associated with actual threat of collision (false alarms). Given the geometric and operational characteristics of work zones, there may be very real limits on how effective any intrusion alarm can be.

Merely alerting the worker is of little value if he does not have sufficient time to react. There may be some need for worker training so that the meaning of the device is well understood. Even so, however, the reaction to the emergency alarm is not a simple, well practiced response. Rather the sequence of probable actions is: (1) The alarm must be detected above ambient noise and recognized as an emergency signal; (2) The worker will engage in visual search to confirm the validity of the signal and direct his actions. This will primarily be search for the errant vehicle, but could also include viewing the actions of other crew members; (3) The worker must detect the vehicle, estimate its course, and determine if a real threat exists; (4) The worker must orient himself with respect to the environment and determine the alternative responses that exist, given the work area layout and the speed and heading of the vehicle; (5) A decision must be made about the which response to take; (6) The response must be initiated; (7) The evasive action must be successfully completed prior to arrival of the vehicle.

Reaction time to emergency signals is difficult to measure in a meaningful way, and we do not have any data that would permit a reliable estimate for this situation. However, if a vehicle travelling 50 mph encroached at the <u>beginning</u> of a <u>200'</u> taper, less than three seconds would be available for the entire response sequence; less time would be available if the intrusion occurred farther into the taper. Most intrusions at the nose of the taper or just at the cone array itself are probably minor incursions and would represent false alarms. If more conservative criteria for intrusion were selected, the response time would be very brief. Under some operating conditions, an intrusion alarm might be beneficial, but in general it appears likely that false alarms will be a serious problem if an adequate warning period is provided. The false alarm problems of annoyance, disregard, work disruption, and intentional signal defeat have already been mentioned. A careful field evaluation of any intrusion alarm system would be required, and the warrants and implementation criteria should be carefully defined.

Application

Some human factors concerns relate to the application of the proposed warning system.

1. The speed control message may be confusing if there is more than one lane of travel in a given direction. Which vehicle is being detected and which driver is being alerted? However it is applied, the visual display should not be ambiguous with regard to the target driver.

2. The optimal location for various components of the system differ. It is not clear where the system itself will be placed or how the individual elements will be deployed. As the MUTCD (6E-8) indicates, the arrow panel is generally used at the start of the taper. However, for the speed control warning, the message would best be located well in advance (e.g. 500') of the taper so that the driver can safely adjust his speed. The speed message, being vehicle specific, and its associated radar, must be at the point of detection itself, not downroad. On the other hand, the encroachment detectors, along with the various suggested alarm devices, must be located along and within the taper essentially all the way into the work area. Thus the array of components, with

connecting cables, could easily span distances of 750 feet or more, and the location of the "body" of the device is unclear. There is at least a conflict between proper placement of arrow boards and speed message boards. The system may be awkward to deploy, control, and trouble shoot in the field. To the extent that the various components of the system are made independent of one another, this submission ceases to the all-in-one transportable package it was initially intended to be. As a package, however, its use may be awkward and impractical if good deployment criteria are used.

Summary

Speed control information may be useful in slowing traffic if carefully designed and implemented. There will be some transient aspect to the response, but steps can be taken to maintain effectiveness. However, adverse driver reactions, and/or unreliable detection, make the speed alarm questionable. The encroachment alarms will face a variety of problems, and may be practical only under limited conditions. Criteria for the use and deployment of the system are unclear but important.

Based on the human factors evaluation this concept was abandoned.

Appendix G

Rumble Strip Designs

Introduction

Rumble strip is the generic name of a group of grooved or raised corrugations placed perpendicular to the path of vehicles and across the full width of the traveled way or on the edge of and parallel to the open traveled way. They produce an audible and tactile stimulus which is felt when driving over them and are intended to alert inattentive drivers of potential hazards that may not be readily apparent, but which require substantial cautionary maneuvers or speed reductions. Rumble strips are more effective for alerting drivers and increasing their awareness than for reducing vehicle speeds.

In work zones, rumble strips are exclusively used in combination with other warning devices such as signs, flashing lights, arrow panels, and barricades. Work zone rumble strips have been used in advance of workers and lane closures; including lane closures leading to crossovers. They have also been used on two-lane roads where one lane is closed and traffic alternates over the open lane.

The geometrical design of rumble strips have been developed for long-term highway construction work zone applications. Maintenance work zone applications have the special requirement of portability. Portability may be achieved either by a reusable rumble strip or a low-cost throw-away rumble strip. In either case, quick installation and removal and reliability while in service are important.

In the case of a reusable design, the method for short distance local movements and the removal, packing, loading and transporting of the strips from site to site must be addressed.

Quick installation and removal could lead to potential safety hazards that are not present in permanent installations. The attachment of the rumble strip to the road surface and the hazard caused by a detached rumble strip is a potential problem.

Rumble strips present other aspects of safety concern. The element of surprise to the driver and the dynamic disturbances to the vehicle may cause the driver to lose control. With the work crew located nearby, the placement and attachment of the rumble strips therefore requires extraordinary care. Rumble strip application will be addressed in the implementation packages developed in Project H-109.

The goal is to develop rumble strips for the following short-term maintenance work zone situations where:

1. Traffic must modify its path such as at a lane closure or traffic shift.

2. Traffic must stop such as on a two-lane highway where one lane is closed and traffic is alternating over the open lane.

3. Traffic must be alerted that it is leaving the open traveled way and entering a closed area such as the transition area, buffer space and work space.

The three types of rumble strips that will be tested to achieve the goals are: traveled way rumble mat, traveled way speed bump, and edge of traveled way rumble stripe.

Traveled Way Rumble Mat

The Traveled Way Rumble Mat (rumble mat) is a rubber mat with hard ridges on the top side (wearing surface) and a smooth, softer under side (friction surface). The device causes tires to rumble (auditory warning) and vibrate (tactile warning), thereby alerting drivers. The auditory rumble also alerts highway workers. The purpose of the device is to alert drivers that they should prepare to perform a maneuver such as changing lanes or shifting laterally in their lane.

Traveled Way Speed Bump

The traveled Way Speed Bump (speed bump) is a mat with bumps designed to give the driver a slight jolt when driven over. The purpose of the speed bump is to alert the driver that the situation ahead may require the driver to stop, such as on a two-lane, two-way road where one lane is closed and traffic alternates over the open lane.

Edge of Traveled Way Rumble Stripe

The Edge of Traveled Way Rumble Stripe (rumble stripe) are strips of synthetic material, 1 to 2 feet wide by 20 feet long with transverse ridges optimally designed to alert drivers that they are leaving the open traveled way and to gently guide the driver away from closed areas. Rumble stripes are colored white for right lane closures and yellow for left lane closures corresponding to the standards for edgelines. They are laid along side channelizing devices in the transition area and buffer and work spaces.

Fabrication and Testing

The seven tasks involved in development of rumble strips are shown in Table G-1. Task 1 was completed in Project H-108 and Tasks 2-7 will be completed in Project H-109.

In Task 1, a design plan was prepared for the rumble mats, speed bumps and rumble stripes. Designs were developed after contacting rumble strip proposers, reviewing an existing synthesis on work zone rumble strips, (Noel, Ziad, Dudek, 1989) consulting rumble strip manufacturers, raised pavement marker manufacturers, rubber product manufacturers, and State highway agencies.

In Project H-109, the plans will be used to contract for fabrication of each device. The devices will then be tested in a closed track setting using first professional and then novice drivers. A device fabricated for testing probably will be different than a device fabricated for commercial production.

Table G-1

Tasks for Rumble Strip Fabrication and Testing

Task 1	
Design Plan Preparation	Contact proposers, review research, contact manufacturers and prepare plans to enable rumble strip fabrication.
Task 2	
Fabrication	Build each proposed rumble strip.
Task 3	
Closed Track Testing	Have professional and novice drivers drive over rumble strips in a number of different vehicles including motorcycles. Conduct vehicle skid tests to evaluate durability and stability.
Task 4	
Closed Track Testing	Eliminate poor designs. Improve designs that show potential. Retest new designs.
Task 5	
Obtain Approval	Make necessary arrangements with FHWA and highway agencies to test rumble strips on highways open to public travel.
Task 6	
Open Highway Testing	Evaluate use in actual maintenance work zones, including set-up time, anchoring methods worker response, and driver reaction.
Task 7	
Implementation Package	Prepare design specifications, operator's guide, and training manual for use of rumble strips in maintenance work zones.

The rumble mats and speed bumps fabricated and tested in Project H-109 will utilize a similar mat. The mat will be about 8 foot long by 12 feet wide and have a series of holes over its area. The rumble bars will be attached to the mat by bolts so that easy assembly and dis-assembly can be done. For example, to produce a rumble mat, the appropriate rumble bars will be attached at a 10-inch spacing. To produce a speed bump, the appropriate rumble bars will be attached at a 5 feet 5 inch spacing. In this way, the optimum shapes and spacings of rumble bars for rumble mats and speed bumps can easily be evaluated. A similar approach will be used on rumble stripes.

Designs will be evaluated using the following performance factors: driver reaction, vehicle handling, stability and movement of the device on the road, vehicle speeds upstream and downstream, service life, portability, durability and deployment time. Based on the results of these tests, the most promising designs will be improved and the least promising eliminated.

After government approval to conduct experimentation, all devices which were successful in closed track testing will be tested on highways open to public travel. State and local maintenance forces will use the devices in actual work zones and evaluate them based on their experience. Implementation packages will be prepared for designs that were safe and effective in open highway testing.

Implementation packages will present performance requirements, general design guidelines and a detailed design. Construction, fabrication, installation and maintenance aspects will be addressed. The implementation packages will also contain instructor's guides, operator manuals, and evaluation guidelines.

Traveled Way Rumble Mat

Description of Device

The Traveled Way Rumble Mat (rumble mat) warns motorists approaching work zones, and warns workers of approaching vehicles and traffic conditions. The rumble mat is a hard, rigid, mat with ridges or bars on one side and a smooth surface on the under side. The mat is 3 to 8 feet in length by 12 feet wide and weighs less than 100 pounds. There will be cut-outs with a smooth finish for handles on each edge for easy handling and for placement on and removal from the roadway.

Two winning proposals were used to develop the rumble mat design. Proposal numbers 287, Safe Speed Reduction Mat, and 187, Portable Rumble Mat were used to develop rumble mat designs.

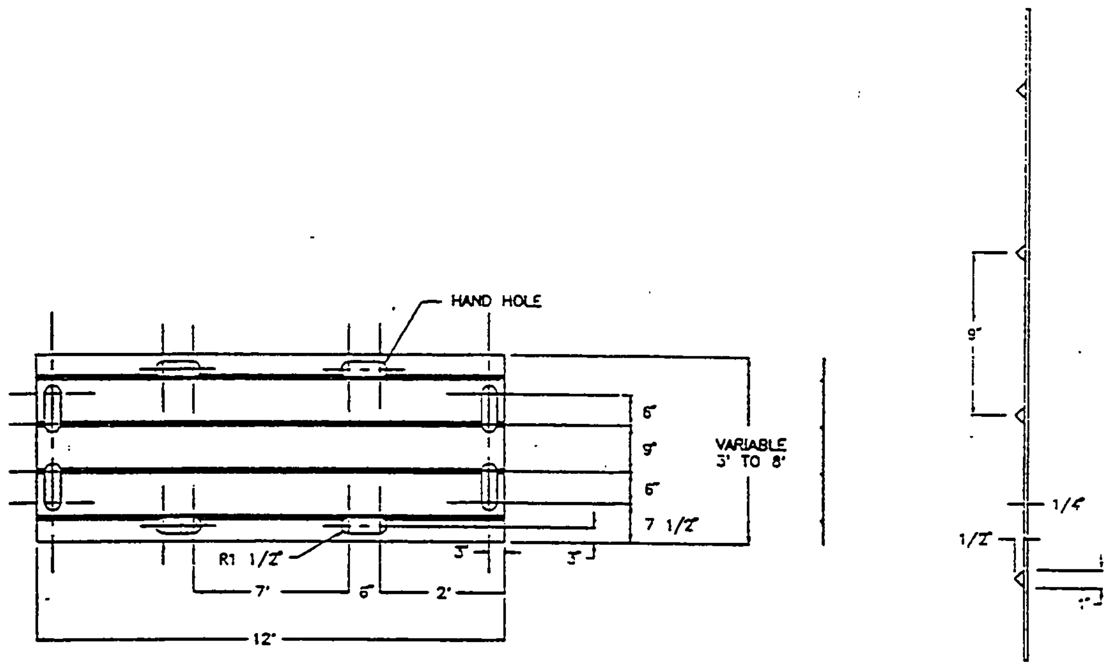
The rumble mat employs materials and technologies that are readily available and in common use in industry today. Three designs will be tested. The first has V-shaped ridges. The second has rectangular shaped bars. The third has rectangular shaped bars made of raised pavement markers. The spacings of ridges and bars will be varied to obtain optimum spacing. Typical spacings in use today are 9- to 10-inches.

The first is made out of heavy fiber rubber. The V-shaped ridges can be made from recycled rubber products such as old tires. It can be formed by using an injection mold process, by tooling the ridges of a rubber mat to a specified design, or by fastening ridges to the mat. In the latter case, ridges would be of material such as V-belts. Figure G-1a shows a diagram of the rumble mat with ridges.

The second rumble mat to be tested is made using a rumble bar developed by the Illinois DOT, and now commercially available. The rumble mat is comprised of six hard rumble bars made of ABS plastic attached to a soft mat and spaced on 10 inch centers. Each rumble bar is comprised of six 24-inch sections. The rumble bar sections are 3 - 1/2 inches wide by 1/2 inch high with a sloped front. Figure G-1b presents a diagram of the rumble mat with rumble bars. Rumble bar sections would be glued to the mat. The weight is approximately 90 pounds.

The third rumble mat has rumble bars made of raised pavement markers. Raised pavement markers are typically 4 inches by 4 inches in area and range from 1/2 inch to 7/8 inch in height. They will be layed side-by-side and glued to the mat.

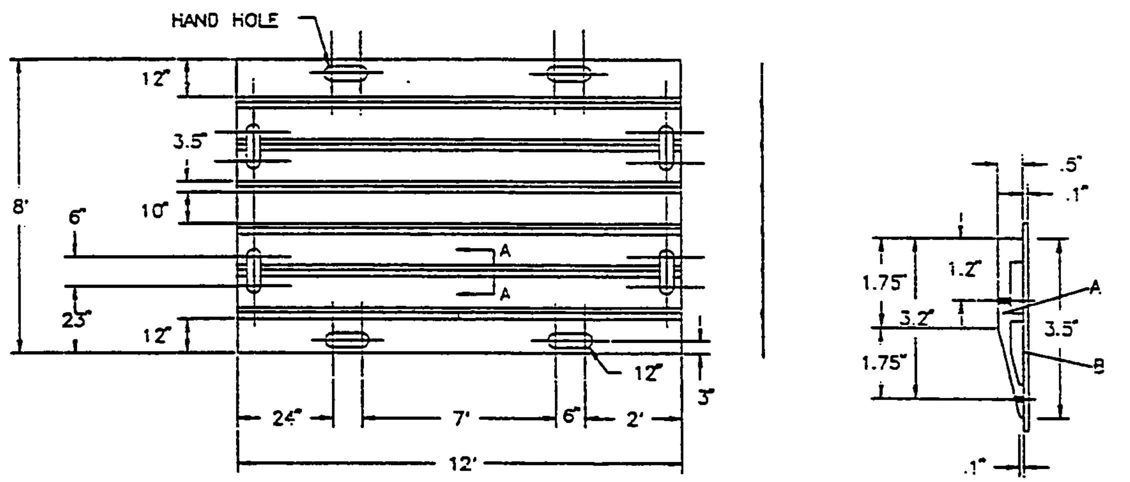
An economic analysis had not been conducted on rumble mats made by molding versus rumble mats made by gluing rumble strips or raised pavement markers to a mat. However, it appears that rumble mats that can be made in-house, such as those made with commercial rumble strips or raised pavement markers, would cost less than rumble mats that must be purchased from a commercial source.



Weight Approximately 80 lb (for 3' x 8' section)

ENLARGED END VIEW

a. Version 1



DIRECTION OF TRAFFIC

RUMBLE MAT ASSEMBLY
wt. approx. 90 lb.

DIRECTION OF TRAFFIC

SECTION A – A

A – RUMBLE BAR IS ABS PLASTIC (HARD).
B – MAT IS ANTI-SKID RUBBER (SOFT).

NOTE: EACH RUMBLE BAR IS COMPRISED OF SIX 24" SECTIONS.

b. Version 2

Figure G-1 - Traveled Way Rumble Mat

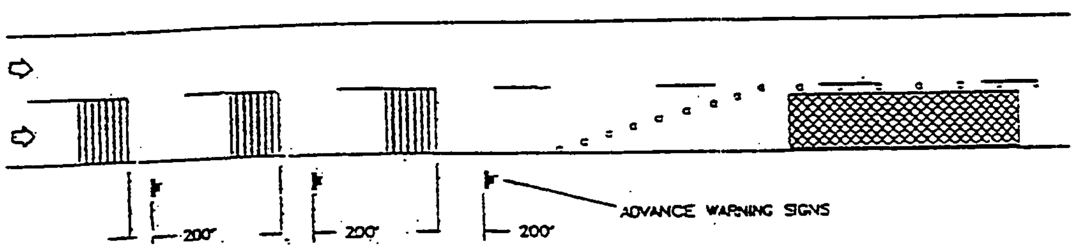


Figure G-2 - Typical Rumble Mat Installation

The rumble mat will alert drivers that they are in a work zone and need to look for warning signs and other directions. The rumble mat will serve as a safety warning device in two ways. The vibrations felt and heard when the vehicle crosses the mat will serve as an auditory and tactile warning. In addition, the highway workers will hear the noise made by vehicles crossing the rumble mat and therefore, alert workers of approaching traffic. In time, highway workers will become accustomed to the sound of vehicles crossing the mat, and be able to identify the speed and location of approaching vehicles. Speed and location information will be beneficial to the highway workers' safety.

Tests will determine if the rumble mat needs to be fastened to the roadway. An optimum design should not require fastening. The rumble mat can be fastened to the roadway in a number of different ways. Double-backed tape or adhesive can be used to secure the mat to the roadway. If necessary, spikes can be inserted through the mat into the roadway when the roadway is composed of loose material such as sand or dirt. If spikes or pegs are used, they can be inserted through the handle areas to secure the mat.

Installation

The pavement should be swept clean before the rumble mat is placed. The rumble mat should be placed in the advance warning area. It can also be placed in the buffer, and work spaces, if needed. Because the mat will be new to the drivers, a RUMBLE STRIP AHEAD warning sign may be placed in the advanced warning area to prepare drivers for their encounter with the rumble mat. The mat is only a temporary warning device and will be removed when the road work is finished or when workers are not at the site.

The rumble mat may weight up to 100 pounds and so requires two people to place on the road. According to the 1987 Illinois MUTCD (Noel, Ziad, Dudek, 1989), a typical installation for a construction zone requires three sets of rumble strips placed 200 feet in advance of each the three respective advance warning signs. Each Illinois rumble strip is 25 feet in length and is comprised of six rumble bars spaced at five feet. Although called "temporary" the Illinois rumble strips are permanent for the life of the construction project.

Figure G-3 presents a diagram of a typical rumble mat installation. Testing will begin with three sets of rumble mats spaced 200 feet in advance of the respective advance warning signs. Testing will determine if fewer sets of rumble mats are sufficient for short-term maintenance operations. In addition, a RUMBLE STRIP AHEAD advance warning sign will be evaluated to determine if it is needed and the effect it has on drivers.

Depending on traffic volume and speeds, installation may require a lane closure or blockage with an arrow panel truck to enable workers to place the mat in the traveled way. A telephone conversation with a researcher revealed that car haulers (large trucks hauling new cars) pulled mats off of the pavement on interstate highways. Rumble mats held their placement better on older asphalt pavements than on new asphalt pavements, because new pavements "bleed" their components more. If needed, adhesives will be utilized to hold mats in place. Experimentation with the composition of the mat material will be done to develop a material that does not move under high-speed truck traffic.

Maintenance

The mats should be checked periodically, say at the beginning and end of each work day, for wear and deterioration. Testing should provide an estimate of mat durability and what it takes to repair a damaged mat. Other maintenance includes cleaning the mat of dirt, particles, and adhesive that would inhibit adhesion to the pavement.

Removal

Removal of the mat from the traveled way requires at least one person to drag the mat off of the traveled way. A high-volume roadway will require a lane closure or blockage so that the worker(s) will have enough time to enter the traveled way and remove the mat. A low volume road may not require the lane closure to enable workers to remove the mat.

Traveled Way Speed Bump

Description of Device

The Traveled Way Speed Bump (speed bump) alerts drivers that they are approaching a work zone situation where they are required to stop. A typical application would be on a two-lane, two-way highway where one lane is closed and traffic alternates over the open lane. Traffic may be controlled either by a flagger or a traffic signal. Proposal number 933, Portable Traffic Warning Speed Bump, was used to develop the design for the speed bump.

As the driver's vehicle goes over the speed bump, the vehicle receives a light jolt. It is more of a pronounced feeling of the vehicle driving over a bump in the road surface than the vibration felt from the Traveled Way Rumble mat.

To obtain jolt, the bumps are higher and spaced farther apart than on the rumble mat. Three types of bumps will be tested. Figure G-3 shows the speed bump using bumps with a semi-circular cross section and shows the bumps with a triangular cross section. The third speed bump will be made using raised pavement markers. If the speed bumps (rumble mats also) has an adverse effect on motorcycles, an open area free of rumble bars will be left for motorcycles to drive through.

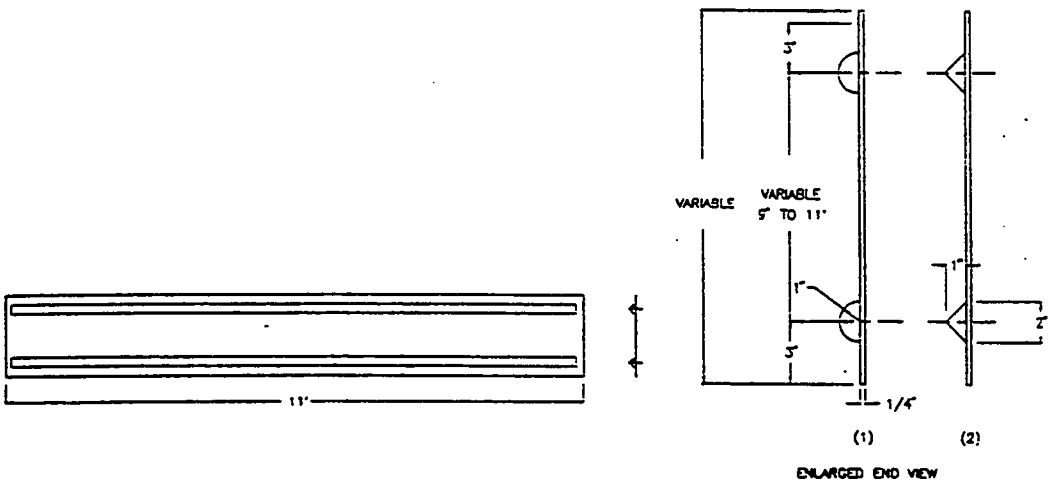


Figure G-3 - Traveled Way Speed Bump

Work done by the New Jersey DOT showed that the maximum jolting effect was obtained when the rumble bars were spaced at 125 inches. But the optimum jolting was achieved at a 5 feet 5 inch spacing. These results were obtained using a rumble bar 1/2 inch high by 3 inches wide with edges beveled at 45 degrees. The research was conducted in the 1960s and was based on vehicles of that period. The wheel base of a typical car of that period was larger than the wheel base of today's typical car.

The height of speed bumps tested will be in the 3/4 - to 1 inch range. Commercial 4 inch by 4 inch raised pavement markers are available with a total height of 7/8 inch.

Installation

The installation, maintenance, and removal of Traveled Way Speed Bumps are the same as for Traveled Way Rumble Mats.

Edge of Traveled Way Rumble Stripe

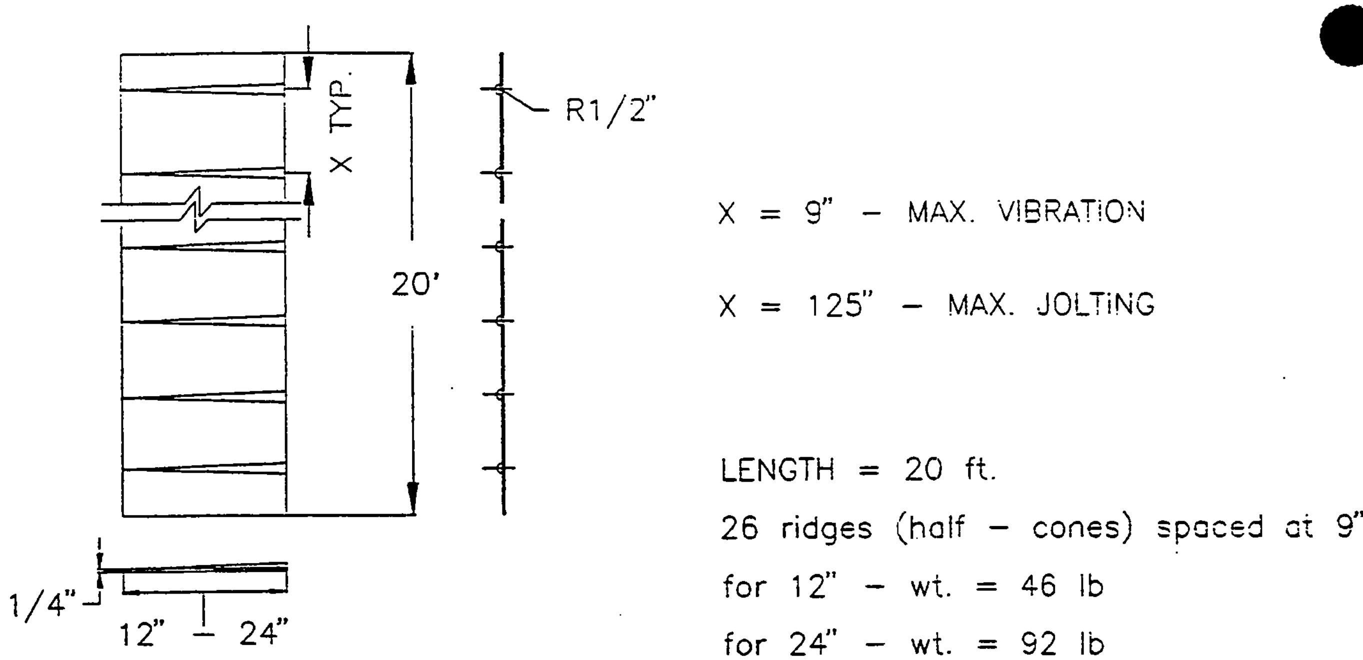
Description of Device

The Edge of Traveled Way Rumble Stripe (rumble stripe) is used at the edge of the open traveled way along the transition of channelizing devices, buffer space, and work space. It delineates and separates the open traveled way used by the motoring public from the closed areas used by workers, work vehicles, and equipment. Figure G-4a shows an example of a Edge of Traveled Way Rumble Stripe. Rumble stripes are constructed of strips of synthetic material, one to two feet wide by 20 feet long, with transverse ridges are optimally designed to alert drivers that they are leaving the desired traveled way and to gently guide them back.

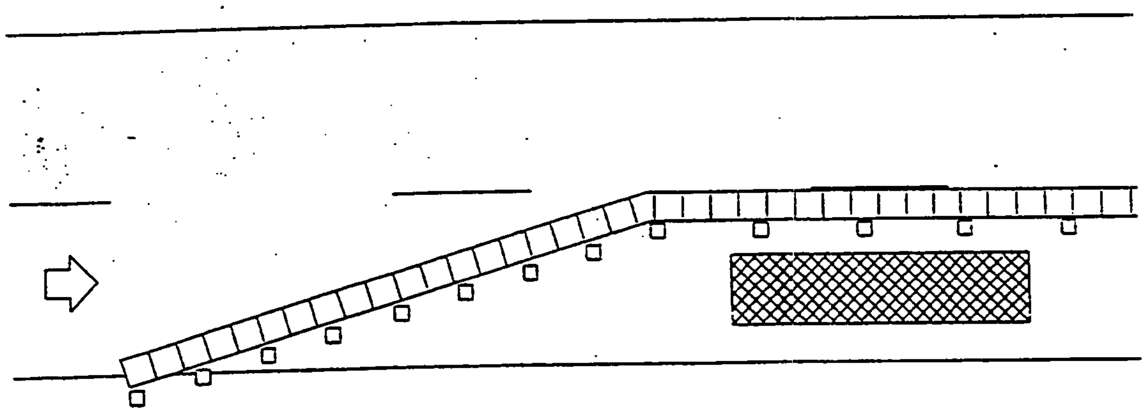
The alert would result from both an audible sound that could also be heard by workers and a vibratory effect on the steering wheel of the vehicle. Testing will determine the optimal shape for the ridges that would produce the rumble and gently steer the vehicle back into the open traveled way.

Figure G-4b shows an example of a typical rumble stripe application. Rumble stripes are colored white for right lane closures and yellow for left lane closures according to standards for edge lines. They would be laid along side channelizing devices on maintenance operations of a medium to long-term nature. Rumble stripes may need to be secured to the pavement with tape or another type of adhesive and would be salvageable for reuse after the operation was over.

The rumble stripes will act like the rumble strips used on shoulders. That is, they alert the driver that he is driving off of the traveled way. A typical shoulder rumble strip design relies more on tactile stimuli rather than audible stimulus and may be as high as 3/4 inch or as deep as one inch. Drivers have complained about these types of rumble strips and have even stopped to check their vehicles for damage and mechanical failure after driving over them.



a. Rumble Stripe Design



b. Typcial Application

Figure G-4 Edge of Traveled Way Rumble Stripe

While the rumble stripe should provide an abrupt alert to a driver encroaching into a closed area, it should not be so severe as to startle the driver into making a panic maneuver to regain control of the vehicle. The design of the rumble stripe should be such that the driver is alerted and automatically, preferably without having to steer, is guided back into the open lane.

There is another concern that the rumble stripe design should accommodate the errant vehicle that drives up and over the higher, outside edge. In effect, the vehicle just went over a small drop-off of about one inch (similar to a pavement shoulder drop-off).

The inside of the tire will scrub against the edge of the rumble stripe as the driver attempts to steer back into the open lane. Normally, the tire should not have much difficulty climbing back up a one-inch drop-off. However, if the rumble stripe is not securely attached to the pavement, the rumble stripe could be pulled off of the pavement and become entangled under the vehicle or thrown into the open lane; creating a potential hazard. Testing will evaluate shapes that forgive an errant vehicle.

Raised pavement markers will also be used to construct rumble stripes. They have built-in reflectors that provide good nighttime delineation. The key is to have a spacing of markers that alerts drivers and guides them to the open lane.

Another device, the Delineator Hose, was proposed as a delineation device. A modification of the device will be developed and tested along with the rumble stripe. The device, known as a Delineator Stripe, will utilize a mat material 1/4- to 1/2 inch thick. The mat will be the same material as that described above.

A commercial pavement tape, such as the Scotch-Lane™ Pavement Tape Detour Grade, from 3M company will form the retroreflective surface. It is highly reflective, conformable, pliant polymer marking material intended for longitudinal lines, and word and symbol applications. The tape consists of a mixture of high quality polymeric materials, pigments, and glass beads, with a reflective layer of beads bonded to the top surface. The tape is reinforced by a non-metallic medium.

The design will provide both visual and physical delineation of the edge of traveled way. The flexible rubber mat will have notches along its length to enable it to be wound on a large reel.

Installation

Rumble stripes can be installed by hand or from a large spool and unrolled, similar to laying underground telephone cable. If installed by hand, a 20 foot section is about the maximum length for a rumble stripe 24 inches wide, since the weight will be about 91 pounds. A 40 foot section of 12 inch wide rumble stripe will also weigh about 91 pounds.

Each coiled section would be unrolled adjacent to the channelizing devices starting at the beginning of the taper and proceeding down stream. Rumble stripe deployment can be done in conjunction with deployment of channelizing devices. On high speed highways with speed limits above 45 miles per hour, 20 foot sections will divide equally into taper lengths. That is, an equal number of sections will fit along the taper. For example, at 55 mph, taper length = 660 feet (660 ft/20 ft/section = 33 sections).

For 40 foot sections of rumble stripe, an uneven number of sections would be required for the taper. The rumble stripe deployment would begin on the shoulder or sections of odd length would be needed to fill-in the space at the end of the taper. Of course, taper lengths can be increased to accommodate rumble stripes at the end of the taper. Rumble stripe is then deployed downstream along the buffer and work spaces.

Maintenance

Maintenance of rumble stripes is similar to that of rumble mats. They should be checked for damage. In the event that the rumble stripe is struck by an errant vehicle, its alignment must be checked.

Removal

The rumble stripe would be removed starting at the downstream end of the work zone along with the channelizing devices. It is envisioned the special spools will be developed that would enable rapid deployment and removal of rumble stripes from the roadway.

Appendix H

Delineation Device Design

Introduction

Area 4 consists of seven types of delineation devices ranging in size from a Moving Taper 300 feet long, which trails behind a maintenance vehicle, to small devices such as the opposing traffic lane dividers which are placed on the pavement in a maintenance work zone.

The Retractable Transition Device is also designed to be placed between two moving maintenance vehicles.

Two new types of barricades are included as well as a new type of channelizing device called a "Caltrop" shaped like a toy "jack."

The seven tasks involved in development of these delineation devices are shown in Table H-1. Tasks 1 and 2 were accomplished in Task 4 of Project H-108 and Tasks 3-7 will be accomplished in Project H-109.

The first task of the development of delineation devices was human factor studies of the originally proposed devices. These studies were appropriate for the study areas that were developing new traffic control devices. The human factors

Table H-1

Tasks for Delineation Device Fabrication and Testing

Task 1 - Human Factors Studies	Review relevant research and poll drivers to determine potential of proposed delineation devices.
Task 2 - Finalize Device Designs	Based on human factors studies, generate final designs for each device including supports and mounting.
Task 3 - Fabricate Device	Build enough devices to permit testing in typical work zone array.
Task 4 - Test Devices in Closed Track Environment	Conduct day and night test of devices in typical array in closed track work zone. Eliminate ineffective designs.
Task 5 - Crash Test Devices	Conduct simple crash tests of device as typically installed in work zone.
Task 6 - Test Devices in Open Highway Environment	Obtain approval for experimentation and test devices in actual maintenance work zones.
Task 7 - Implementation Package	Prepare guide to use on delineation devices in maintenance work zones.

studies investigated the driver tasks related to each device, the expected benefits of the device, problems or concerns, unknowns, design considerations and the overall prospects for behavioral effectiveness.

The information contained in the human factors studies led to abandoning of some concepts and modifications to other original proposals. Based on the human factors studies the retractable transition device and the caltrop were abandoned. The delineation hose was combined with the rumble stripe concept discussed in Appendix G.

The human factors studies of each device are detailed below. Design details are also discussed for all accepted devices.

Moving Taper

Human Factors Evaluation

Driver Task as Related to the Device

From the driver's perspective, the task is no different than with any other taper array of cones. Presumably the cones employed are visually identical to normal traffic cones. The major task of human factors concern is that of the operator who must maneuver the taper, keeping it in proper alignment at all times. To the extent the operator is unsuccessful at this, the driver's visual task may become more complicated. The driver would have to recognize the intended path to be delineated, and recognize the need to change lanes and the amount of space available for this maneuver.

Benefits

The benefit of this device is that it provides a constant means of channelization for moving operations or stop-and-go operations. It also means that personnel do not have to be put at risk when putting cones in place.

Problems/Concerns With The Concept

There are a few human factors concerns with the basic concept of this device. First, since the taper is constantly moving, rather than being set up for a particular site, it will sometimes be located in inappropriate locations. For example, the cones may begin just beyond the crest of a vertical curve, around a horizontal curve, or other limited sight distance situations. In such cases the cones will not only fail to provide advance warning and delineation, but may themselves be very difficult to avoid hitting.

A second problem is that a driver approaching the taper will also see a moving vehicle travelling normally in the lane ahead. In this sense, the visual cues from the maintenance vehicle contradict the cues provided from the taper itself. This might prove confusing to the driver, but of even more concern, it may simply cause a perceptual failure to appreciate the presence and significance of the cone array. A vehicle travelling in the lane ahead is a normally valid cue that the lane is open.

Finally, there is a tradeoff between the maximum length of the taper and the mechanical tradeoffs of a longer device, since the taper must be long enough to accommodate traffic speed. A normal stationary taper for a 12 ft lane and a 65 mph speed limit would be 780 feet. It is not known if a moving taper could be shorter and still furnish effective delineation. There may be a problem if the taper is too long for conditions such as an urban street with numerous driveways and intersections.

Unknowns

It is not known how a longitudinally moving display of cones might affect driver perception of speed, distance, or path. It is easy to imagine that this might induce visual distortions or illusions, and possibly be disorienting on curves. Since driver speed relative to the cones is less than speed relative to other delineation, the moving array could conceivably lead drivers to feel they are going slower than is actually the case. However this is speculative since this novel situation appears to have been untried. It is recognized that most mobile work activities will be moving at low speeds, and presumably whatever perceptual distortions can occur would be speed related. However, the question of what the device does to driver perception, especially at the upper end of the anticipated travelling speeds, will have to be carefully evaluated.

Design Considerations

There are two sets of human factors design considerations. One set concerns the operational control of the moving taper by the maintenance personnel. The second set concerns the effectiveness of the display for the approaching driver.

Considering first the control of the articulated taper by a person in the truck, the question is, can it be appropriately controlled, over its length for all of the geometric features likely to be encountered? Since the control mechanism is not really explained in the original proposal, it is not possible to comment directly. However, the significance of the problem may be better appreciated by noting an accurate depiction of the relative size shown in Figure H-1. In this figure the moving taper is about ten times the length of a 30-foot vehicle). How accurately can the operator, presumably sitting in the rear of the truck, control the far end of this array? How much training will be needed? How often will the latter part of the array be out of sight (curve, crest)? Is the taper rigid in either the horizontal or vertical dimension? If so, how will it respond as the device is dragged over a crest, through a sag, or around a sharp curve? What will happen if the maintenance vehicle driver has to brake sharply?; will the momentum of the cones cause the array to buckle or tangle, and could the operator do anything to control this? The mechanics of operator control is a significant design issue to be addressed.

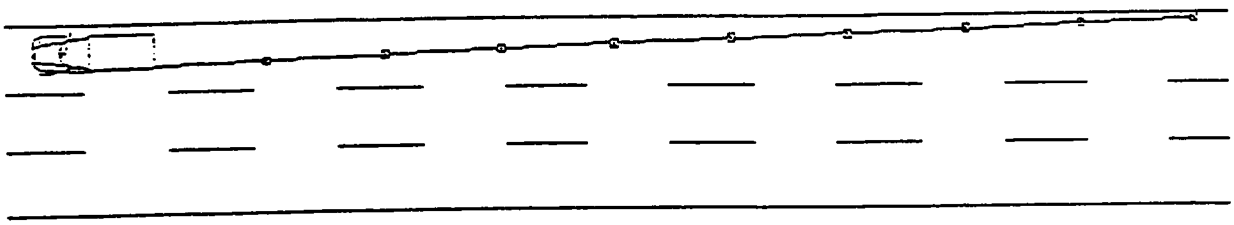


Figure H-1 - Moving Taper

From the following driver's perspective, there are also design issues. First, the spacing of cones, in order to provide a good path cue, is speed dependent. The MUTCD describes a maximum spacing that is approximately equal, in feet, to the speed limit. Presumably, this spacing will not be readily adjustable on the taper. Therefore some fixed spacing will have to be selected that will be maximally effective for the range of speed limits foreseen. Since the lowest speed limits will largely drive this decision, the device may have to incorporate many more cones than required for higher speed limit applications. This might have repercussions for storage, portability, and cost.

The moving taper will also have to be designed so that the cones remain relatively stable. If they waver, shake, and wobble as they are pulled, they may be visually degraded as path cues, and might even be disturbing or disorienting to drivers. However, it must be said that it is not known whether this will actually be a problem. Nonetheless it appears most reasonable to require that the individual cones remain relatively steady.

A final consideration concerns what happens when a motorist collides with a cone, which will inevitably occur. If a driver hits a traditional cone, there is relatively little impact and not much difficulty in terms of vehicle control. The cone falls or is dragged, but this does not influence the rest of the delineation array. However, it is not at all clear how the design of the proposed device will influence this situation. Since traffic cones are routinely hit, design aspects should carefully consider the effects of minor collisions with the cones and/or semi-trailers.

Summary

Some major unanswered questions make the potential effects of the moving taper on driver behavior unclear. It may be that the concept has most promise for low speed work areas, with good sight distance; this would minimize the concerns about operator control, driver detection around vertical and horizontal curves, and perceptual distortions. However, key design features will need to be carefully evaluated before the appropriate applications, if any, can be determined.

Description of Adopted Design

The Moving Taper is a device which carries a row of traffic delineator cones which are configured in a taper. The device consists of 20-ft long semi-trailers that are hitched together. The overall length is 300 ft, but additional semi-trailers could be added or removed to adjust the length of the taper. Each semi-trailer is constructed of two fiberglass I-beams running the length of the trailer. Cross beams are used for internal support of the frame and casters are used for supporting the rear end of each semi-trailer. One cone is secured to each trailer just above the cross beam.

The Moving Taper has two methods to allow it to maneuver in a highway environment. The primary control is the rear steering equipment which is mounted on the end of the last trailer. This allows the taper to be steered along the road shoulder or to track along a highway lane. The second means of control is bow control. This allows the Taper to be bent so that it conforms to the curvature of the highway. The combination of these two control methods allow the taper to be maintained while the trailers move along a curved section of highway.

Detailed Description

The moving taper is made of a series of 20 ft long semi-trailers. Each trailer in the taper is the same except for the controls on the front and rear units. The main members of the trailer are 4 in by 4 in by 1/4 in fiberglass I-beams. Two of these beams run the full length of the trailer, and are attached together with 3-in cross beams, front and rear hitch plated and a channel which mounts the casters to the assembly. Figure H-2 depicts the plan view of a semi-trailer. The 3-in cross beams are used every 5 ft, and attached to the main beams using standard fasteners. The tires on the unit are fully pneumatic 9.3 in tall and 2.80 in wide. The wheels are 2.5 in diameter. These small units were selected as the best compromise of low profile for minimizing potential accident damage from encroaching vehicles and pneumatic devices for long life and smooth ride. The tires are supported on a 6 in fiberglass channel which mounts to the top of the frame through two spacers.

The semi-trailers are attached together using a hitch and pin arrangement. The hitch is made of 0.5 in fiberglass plates. The front end of each semi-trailer has a single plate attached to act as a tongue for the trailer. The rear end has a yoke with a hole for attaching two units together using a 1 in draw pin.

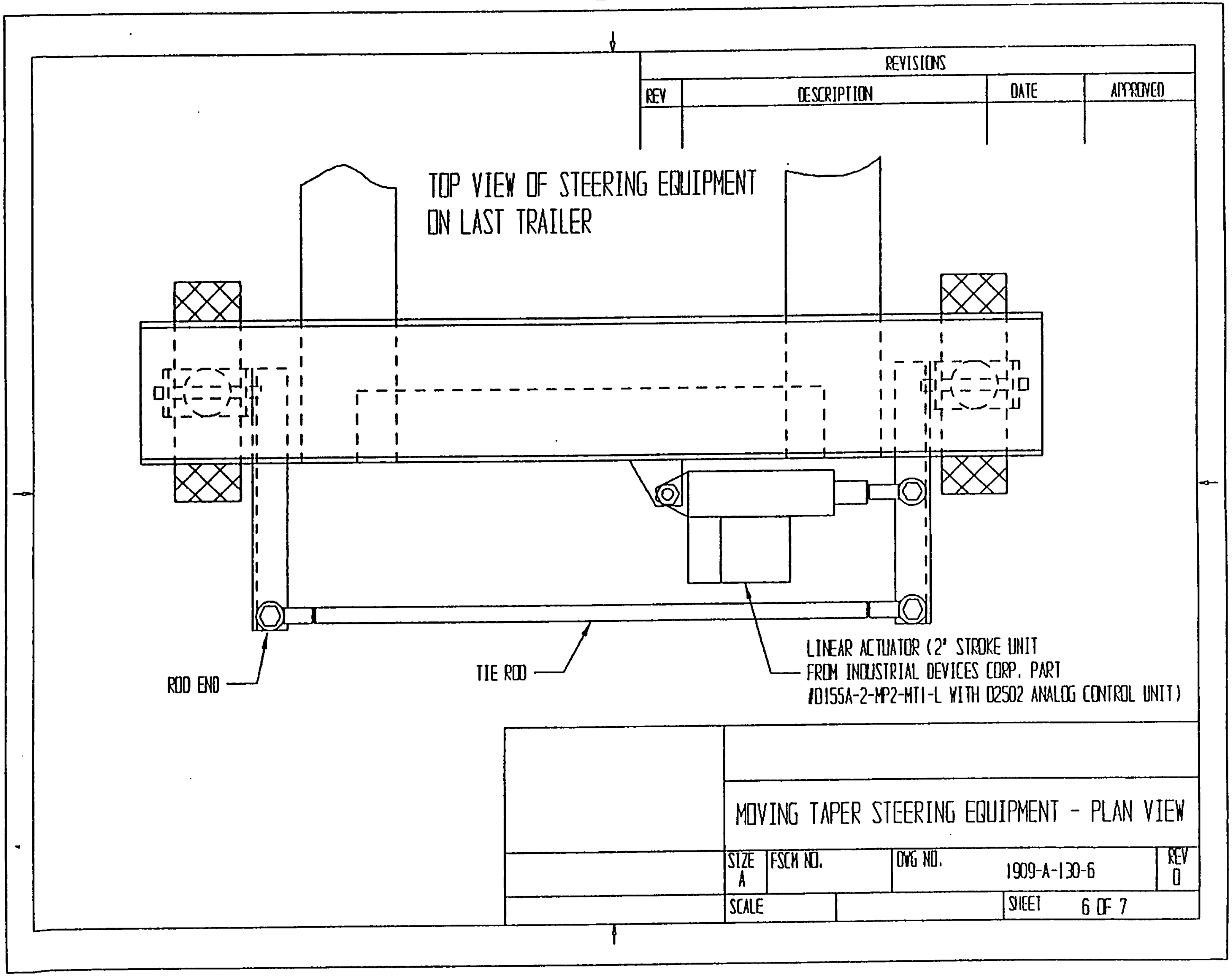


Figure H-2 - Depicts the Plan View of a Semi-trailer

Laboratory testing will determine the necessity of placing metal inserts on the fiberglass holes for the draw pin to act against.

Bow Control

To control the bow in the Moving Taper, a set of tension springs and a control cable are used. The tension springs are placed in sets across each hitch between the semi-trailers. They are used to maintain the semi-trailers in a straight line and add a restoring force to change the angular orientation of the trailers based on the input from the control cable. The control cable is 0.25 in overall diameter including the plastic coating and is constructed of galvanized wire rope. The cable runs the full length of the Moving Taper along both sides. It is held to the outside edge of the I-beam using 0.25 in pipe straps. These will act as stand offs and guides for the wire rope. At the end of each semi-trailer, loops will be installed in the control cables to allow for disconnecting the trailers from each other. Quick disconnect spring hooks will be used to connect the control cables between the trailers after they are hitched together. After the trailers are hitched and the control cables attached, the slack in the control cable is adjusted using two small hand winches. These winches are located on the last trailer.

A control device is installed on the front trailer to vary the length of each cable and thereby control the bend in the trailers. The actuator is an electric operated device with 18 in of stroke. The linear actuator is mounted to one of the 4-in fiberglass beams which run along the trailer. Attached to the actuator is a fabricated yoke which allows a control cable to be attached to each end.

Using this approach, the same actuator is used to move both cables. The far side cable is connected to the actuator by routing it around two cable blocks located in front of the actuator on both I-beams. Control of the actuator is accomplished using an analog controller.

Steering Control

The rear semi-trailer has a set of steerable wheels. These allow the rear unit to be steered to control the lateral position of the Moving Taper. The steering is accomplished using the same casters as on the other trailers. The side frame of the caster is fitted with a small aluminum angle which acts as a steering arm. An electric actuator is used to move the steering arm and change the steering angle of the wheels. Both wheels are connected together using a tie rod with spherical rod ends on each end. The actuator has a stroke of 2 in. The actuator will be controlled using an analog controller

Actuator Control

To operate the actuators, the operator in the tow vehicle adjusts the Position Control on the control device for the desired position of the actuator for the desired function, bow or steering. As the piston moves in and out a sensor internal to the cylinder sends a signal to the controller relaying its position. The controller compares the output of the Position Control and the signal sent from the actuator. A comparator within the controller sends a signal to the servo motor to extend or retract the cylinder until the two signals are equal.

Power for the system comes from a 24v battery, or from a 24 vdc system on the tow vehicle. Cabling for the two actuator systems consists of protected cabling and connectors near the hitch point of each trailer. This allows the trailers to be disconnected for storage and transportation.

Installation

The trailers will be trucked to the site and assembled. The trailers will be hitched together using the following procedure. The hitch pin is inserted to link together the first two trailers. The tension springs are then attached to each trailer. The first of the tension springs will be easy to attach because there is no pre-load on the spring. The second spring is attached by bending the trailers such that the first spring is extended and the distance for attaching the second spring is reduced so that is can be easily attached. The curvature controls cables are then linked together by clipping them together using spring hooks. The electric control and supply cables for the actuators are then connected together (each trailer has it's own section of cabling). This procedure is used to link together all the trailers is succession. After the trailers are all hitched together, the hand winches on the last trailer are used to remove the slack from the curvature control cable.

Operation

The Moving Taper is operated by second person riding on the rear of the truck. The operators panel will consist of two rotary knobs which will control the steering and bow. After initial setup of the consist, tow the taper in a straight line. After the units have stabilized in a straight path, operate the steering control to move the rear of the system to the shoulder. This is the standard operation for a tangent roadway. When the taper enters a curve, use the bow control to curve the unit to conform to the local roadway curvature.

Closed track testing of the maneuverability of the moving taper will be conducted to reveal how well the bow control will operate for curves with varying degrees of curvature. These test will also reveal how difficult it will be for one person to both steer and bow the deployed taper.

Retractable Transition Device

Human Factors Evaluation

Driver Task as Related to the Device

As a channelizing device, the retractable transition device serves a similar function to cones or barricades. The driver must detect the presence of the device, understand that it indicates a lane closure and the need for a maneuver, recognize the path being delineated and comprehend his vehicle's proper position relative to this path. All of this must occur with sufficient time and distance to permit a safe change of lanes, presuming the presence of other traffic.

There are also human factors aspects to the task this device would pose for maintenance personnel. It is not at all clear how the spooling and rewinding mechanisms would be operated, and if this can be done from the truck cab. Since one of the stated benefits of the concept is that the maintenance personnel do not have to be exposed to risk as pedestrians, we presume that somehow the device can be controlled from within the vehicle. The exact tasks that the mechanism poses for operators of the two connected maintenance vehicles are not clear, but there will probably be some human factors considerations.

Benefits

Because the band of delineation material winds and rewinds on a truck-mounted spool, deployment and retrieval of the device should be fast and simple. Since deployment can be accomplished from a truck, maintenance personnel are not at risk as pedestrians on the roadway when placing delineation. Also, because there is no array of separate devices, as there is for cones or barricades, individual devices do not have to be set up and then maintained. The benefits of rapid deployment and removal will be especially advantageous where there are short-term work activities.

The original proposal indicates that the retractable transition device would also have advantages for the approaching drivers. It is claimed that this concept would provide a simple, clearly understood, channelizing device. However, there are a number of concerns related to the perception of this device which question its benefit to motorists as an alternative delineation method.

Problems/Concerns With the Concept

There are a number of rather significant concerns with the basic concept. One has to do with the visibility of the delineator band. For a vehicle approaching from behind the trailing shadow truck, the truck itself may obscure most of the view of the retractable band. Figure H-3 is meant to give some feel for this problem. While many different conditions could have been illustrated, the drawing represents a reasonable case. The two maintenance trucks are shown deploying a 100' taper of the retractable band. An approaching vehicle is shown 60' behind the trailing truck. The approaching driver's approximate line of sight is sketched as the dashed line. As the illustration suggests, only a small lateral distance is covered by the delineation band. Intervening traffic in either lane could further limit the view for this driver. It is clear from this example that the rear of the trailing truck must be included as part of the warning system, for example with an arrow panel.

Another inherent problem may be that the retractable band blocks drivers' views of the rear of the lead deployment truck. At least the right side brake lights, and possibly both sides, would apparently be obscured by the band of material. Some additional vehicle lighting would therefore be required, but this may not communicate as well as the normal vehicle lamps.

An additional problem comes about in night viewing. The submission indicates that the chevrons on the retractable band would be "reflective." The reflective chevrons may not provide adequately sized visual targets under the oblique viewing conditions (see "Design Considerations"). There is also the assumption

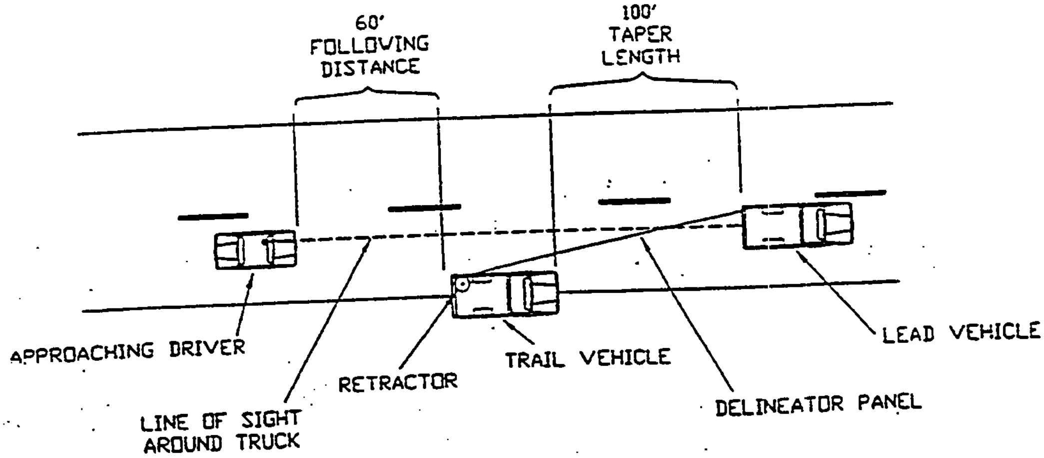


Figure H-3 - Retractable Transition Device that a suitably flexible retroreflective material exists, which is able to withstand the repeated rolling and unrolling from the spool. However, the greatest concern has to do with limitations to the performance of the retroreflective material. As Figure H-3 makes clear, the viewing angle between the delineation band and the driver line of sight (and headlight beam axis) can be extremely small. The angle will depend on the length of the taper and the position (lane and distance) of the approaching vehicle. However it is clear that under many conditions the geometry of the situation will place the headlight beam entrance angle well outside that for which the retroreflective material can provide a good response. As the angle of the headlight beam ("entrance angle") deviates from zero degrees, the efficiency in returning reflected light back along the viewing path begins to roll off. The sharpness of this roll-off depends on the type of material, but clearly the entrance angles to be anticipated in the field will be extreme relative to this performance. In combination with the potentially restricted view of the delineator band, already discussed, this would seriously limit nighttime effectiveness.

Yet another problem might have to do with the driver expectancies created by the deployment system. To the approaching driver, there is a view of two vehicles in the lanes ahead, one leading the other. The immediate impression might be that traffic is travelling in the lanes ahead, i.e. the lanes are open. The delineator band must "contradict" this impression. Therefore something must be done to enhance the message that these are not normal vehicles in the traffic stream. For example, large flashing arrow panels on the rear of the trucks may be required. However, as such additional traffic control devices get added, the unique aspects of the proposed design become diminished. The retractable band now no longer serves any significant alerting function or indication of a required maneuver, but just a channelizing role.

Another concern with the concept addresses the potential safety and cost. Two trucks must be dedicated to the site strictly for channelizing purposes, which involves a commitment of resources. These trucks, being on the road, represent collision hazards. Although the submission indicates that the trucks are equipped with crash cushions, the injury risks to colliding motorists, as well as potential operational problems following collisions, are certainly much greater than with cones or barricades. Another question relates to the consequences of an errant vehicle colliding with the band of material. What effects will this have on the material and/or the impacting vehicle? Will the delineator band tear or unspool? Could it "blind" the driver by wrapping around the windshield, making recovery of vehicle control difficult?

Finally, it is not clear if the intended application of the concept is only for short duration and stop-and-go maintenance activities, or if it is intended to include moving work zones. If moving work zone applications are contemplated, the drivers of the two maintenance vehicles will have to maintain identical speeds; otherwise the fabric will sag and twist, or unreel further. It is not clear how this precision driving will be accomplished, particularly since the band will obscure the trailing driver's view of the lead vehicle, including the rear brake lights. If for any reason either vehicle must brake suddenly, the delineation band will be disrupted. Thus there seems to be potential problems in applying this concept to moving work zones.

Unknowns

There are no "unknowns" related to human factors aspects for the basic concept

Design Considerations

As portrayed in the original proposal, the conspicuity and legibility of the device will be seriously lacking. Even ignoring the considerations already discussed, there are two design aspects which must be addressed. One is the width of the band of material. The submission indicates a 12" band, which is clearly too small. Compared to field practice for alternative TCD's such as traffic cones and signs, the dimension must be at least doubled. It still would not be expected to have the target value of an array of discrete high-visibility objects.

Furthermore, the chevron pattern on the retractable band will not be effective in its normal form. The oblique viewing angles will cause a very foreshortened image. Each chevron itself will appear as a very thin, almost straight, vertical line. The appearance can be improved by longitudinally elongating the chevron shape, in the same manner that pavement word markings (MUTCD Section 3B-17) are "stretched." However, because the taper length will be variable, the appropriate degree of elongation will vary with the application, as well as the presumed driver location (which lane the approaching vehicle is in). It should be recognized that depending on how the spools are mounted on the maintenance vehicles, and factors such as lane width, the maximum lateral span of the band is unlikely to exceed perhaps 18 feet, with something in the range of 15 feet more likely. Furthermore, much of the right side of this will be obscured to approaching traffic by the trailing maintenance vehicle itself. Therefore the "effective" width of the display probably should be assumed to be no more than approximately 9 feet. How many chevrons should appear on a sign display that is 9 feet wide? Probably four at a maximum. Depending on the maximum length of the taper permitted, this 9 foot wide, four chevron display might extend over a substantial longitudinal distance, e.g. 75 feet. This gives some idea of the sort of extreme elongation that might be required to make a legible chevron display for the approaching driver. To the extent that taper length will be variable, the "proper" shape for the markings will be difficult to specify.

Summary

There are some serious human factors concerns with the basic concept of the retractable transition device. The ease of deployment for short term work zones could justify consideration of the device for a very carefully considered and highly limited range of applications. There are serious questions to be answered before the concept should be considered for any general use, and even limited applications may prove to be inappropriate. As delineation, the proposed device certainly cannot stand alone, and some form of additional TCD's, such as arrow panels, would be required on the deployment vehicles.

Based on the human factors evaluation, this concept was abandoned.

Portable Soft Barricade System

Human Factors Evaluation

Driver Task As Related To The Device

This device has little direct implication in terms of driver behavior, since it is an alternative construction for current barricades. From the driver's perspective, the task is unchanged.

Benefits

The device will meet the MUTCD requirements for Type I, II, or III barricades, and function as these barricades normally do. The advantages relate to the lightweight construction, modular assembly, and folding structure of the system. This should result in the benefits of reduced damage and injury potential in the event of a collision with the barricade, easy storage and transport, and ease and flexibility of use.

Another feature is that the barricade panels are attached to "retracting tension devices" which normally keep the panels vertically oriented. However, in winds this attachment permits the panel to rotate, reducing the wind force and the likelihood of the barricade blowing over. This aspect is not well described. It is not clear how far the panels will be able to pivot, and how readily this will occur.

Problems/Concerns With The Concept

Because the key features of this device concept do not generally relate directly to either driver behavior/perception or work crew behavior, there are not many human factors issues to address. However, there are two quite fundamental concerns with the concept, both related to the feature which allows the barricade panel to rotate in the wind.

First, as the panel(s) rotate, the target value is reduced. Because the panel is no longer perpendicular to the driver's plane of view, the visual angle it subtends will be decreased. For example, a panel rotated 45 degrees will present a target of only about 70% the height of a normally oriented panel. Similarly, the foreshortened perspective of the striping pattern on the angled face will reduce its target value; the appearance will be of finer lines (each subtends a smaller angle).

The second concern related to visibility when the panel is rotated concerns nighttime viewing. If a vehicle's headlight beam (and driver viewing angle) are sufficiently oblique, the retroreflective characteristics of the material drop off. The function relating this drop-off to the approach angle ("entrance angle" of the light beam) will depend on the particular characteristics of the retroreflective material, as well as the color of the sheeting. For example, "high intensity sheeting" (FHWA Type IIIB) begins to show a sharp drop in the efficiency of the retroflecting surface as the entrance angle exceeds about 20 degrees. In contrast, "engineering grade" sheeting (FHWA Type II), while less effective than high intensity sheeting at more direct viewing angles, shows relatively little drop in performance even at 30 degrees. To give some sense of the magnitude of the brightness loss that might be encountered with the rotating panel, specifications for different sheeting types from "Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects" (1985) are presented in Tables H-1 and H-2, taken from McGee and Mace (1987). Tables H-1 and H-2 show specific intensity as a function of two entrance angles (-4 degrees and +30 degrees). Two observation angles are also given (this has to do with the angle defined by the separation of the light source [headlights] and the viewer [driver eye position]). The major point is that a 30 degree entrance angle can sharply degrade the stimulus for all colors, including the white and orange that would be found on the barricade panels.

Unknowns

There are no "unknowns" concerning the basic concept.

Table H-1

Minimum Specific Intensity Per Unit Area (SIA) (Candelas Per Footcandle Per Square Foot) for Type II sheeting

Type II Sheeting

Observation Angle (°)	Entrance Angle (°)	White	Red	Orange	Brown	Yellow	Green	Blue
0.2	-4	70	14.5	25.0	2.0	50	9.0	4.0
0.2	+30	30	6.0	7.0	1.0	22	3.5	1.7
0.5	-4	30	7.5	13.5	1.0	25	4.5	2.0
0.5	+30	15	3.0	4.0	0.5	13	2.2	0.8

Type II-A Sheeting

Observation Angle (°)	Entrance Angle (°)	White	Red	Orange	Brown	Yellow	Green	Blue
0.2	-4	140	30	60	5	100	30	10
0.2	+30	60	12	22	2	36	10	4
0.5	-4	50	10	20	2	33	9	3
0.5	+30	20	6	12	1	20	6	2

Table H-2

Minimum Specific Intensity Per Unit Area (SIA) (Candelas Per Footcandle Per Square Foot) for Type III sheeting

A - Glass Bead Retroreflective Element Material

Observation Angle (°)	Entrance Angle (°)	White	Red	Orange	Yellow	Green	Blue
0.2	-4	250	45	100	170	45	20.0
0.2	+30	150	25	60	100	25	11.5
0.5	-4	95	15	30	62	15	7.5
0.5	+30	65	10	25	45	10	5.0

B - Prismatic Retroreflective Element Material

Observation Angle (°)	Entrance Angle (°)	White	Red	Orange	Yellow	Green	Blue
0.2	-4	250	45.5	100	170	45.5	20.0
0.2	+30	95	13.3	26	64	11.4	7.6
0.5	-4	200	28.0	56	136	24.0	18.0
0.5	+30	65	10.0	25	20	10.0	5.0

Design Considerations

From the human factors perspective, the major design considerations concern the adequate compensation for any permitted degree of rotating of the panel face. There will have to be some specified limit to how far the panel can rotate. Whatever the maximum, the panel sizes should be increased so that they present the desired target size when maximally rotated. For example, if a 12" panel would normally be used, 17" would be required to create the same size image if a 45 degree rotation were permitted. Also the striping pattern should be similarly expanded. This would of course present a somewhat "distorted" aspect when viewed from perpendicular. Although this probably would not create a problem, it should be investigated. An alternative approach might be to find other ways to reduce wind force, so that less rotation would be required. For example, it may be possible to design louvers that would reduce wind load without significantly changing the appearance of the panel to the oncoming driver.

The retroreflective material used for the panel face should be chosen to meet the demands imposed by the maximum permitted rotation, so that drivers at night can adequately see the panels even in high wind.

Summary

This concept is not designed to enhance driver performance. The key question is whether its innovative aspect for spilling off wind can be accomplished without seriously degrading driver perception. If the degree of rotation is limited so that design aspects can compensate for the perceptual effects of pivoting, the concept should be feasible.

Description of Adopted Design

Based on the human factors evaluation, the design of the portable soft barricade system was altered. The design alterations involved changing the support mechanism of the barricade, changing the size and pattern of the barricade panels, and designing a limiting mechanism to keep the panels from rotating more than 20°. The revised design of the portable soft barricade system is shown in Figure H-4.

The a-frame design of the upright supports for the barricade were chosen as being more stable than a single upright specified in the original proposal. This design also allows the incorporation of a mechanism on each panel that will limit the amount of deflection of each panel during wind loading.

The size of the panels was increased to 17" x 36" based on the human factors evaluation. The barricade is shown with a non-directional patten, but may also be tested with the normal slanting stripes. The barricade should fold flat for transport.

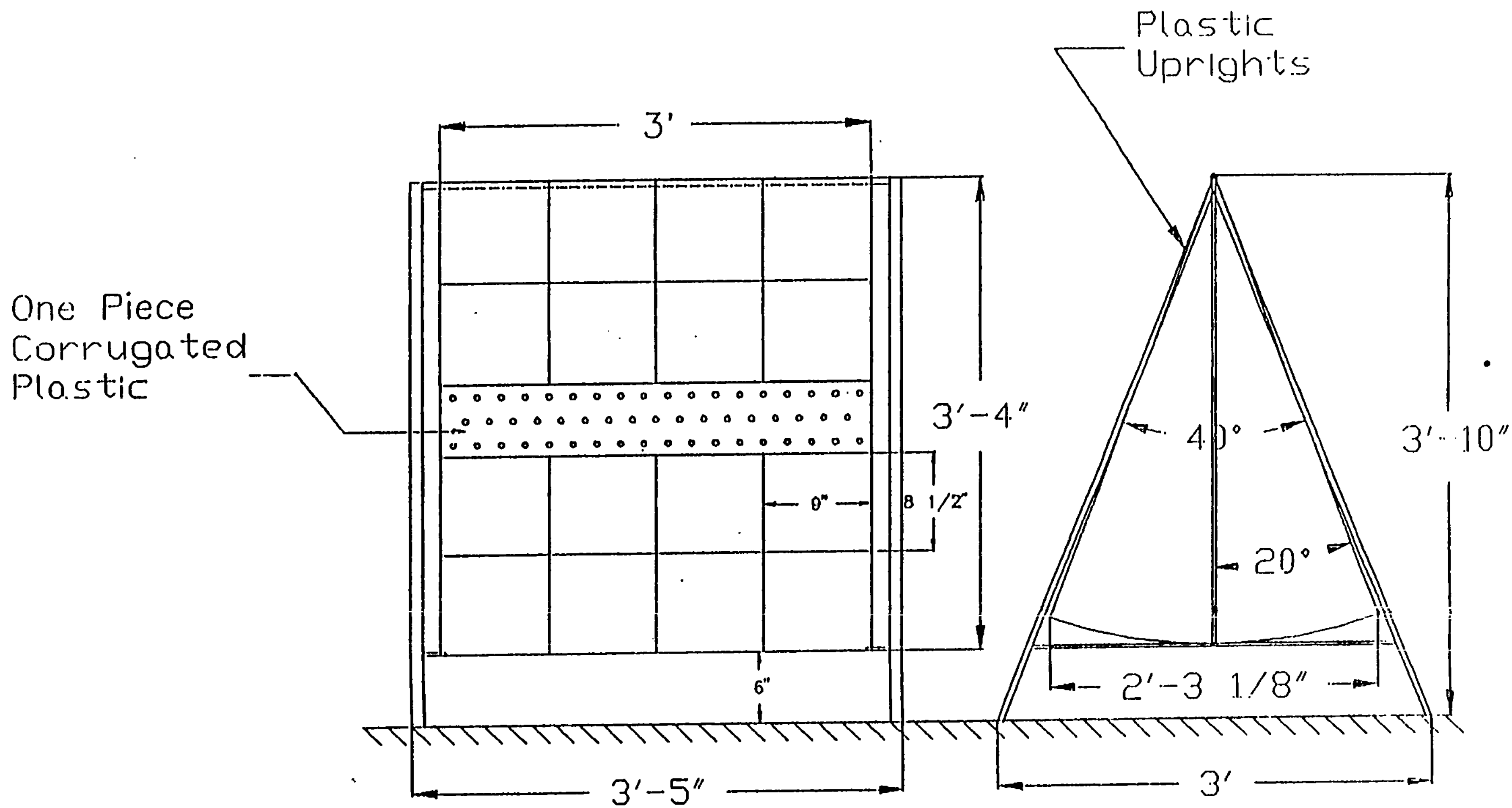


Figure H-4 - Portable Soft Barricade System

Prototype units of the barricade would need to be wind tested and durability tested. The system would need to be used by work crews to determine if it will have field acceptance.

Direction Indicator Barricade:

Human Factors Evaluation

Driver Task As Related To The Device

Barricades are used to mark specific hazards or employed in series to channelize. In order to serve these functions, the approaching driver must detect the barricade(s) and recognize the warning function. Then the driver must recognize the location of the barricade relative to his path of travel, and determine the appropriate path to take. The proposed device modifies the current barricade in an attempt to improve performance in this latter respect, by using an arrow to provide directional path information to the driver. The current diagonal striping (the direction of which indicates the path of travel) is replaced by a non-directional checkerboard pattern, and the directional information is highlighted by an arrow which can appear as part of the center barricade panel, on whatever side is appropriate. Therefore the driver's task, as related to this new concept, must include recognition of the fact that there is a directional indicator within the barricade, and determination of the direction in which it points. The meaning of the arrow, in terms of required driving maneuvers, must also be correctly understood.

Benefits

There are presumed benefits for both the driving public and the maintenance personnel. The submission recognizes that the directional information in current barricades (direction of slant) is not recognized and not understood by most motorists. This has been shown in several studies, and in fact COMSIS' own work (Lerner and Dudek, 1986; Sedney, Walker, Alicandri, and King, 1987) has shown that if people are forced to guess which direction is appropriate, the diagonal striping more often leads to the wrong interpretation. By providing a more readily understood directional cue, the driver may be aided in navigation. Because there is an arrow indicator on each side of the proposed device, the barricade can also represent the condition where traffic can be diverted to either side of a barrier.

The benefit to the maintenance personnel comes from the flexibility of the device. A single barricade can be used for left side, right side, or center lane applications. This could reduce the number of barricades needed in the inventory. It may reduce the inappropriate g$2 use of barricades indicating the wrong direction of travel. And it permits barricades at a work site to be flexibly adapted to changing site conditions.

Problems/Concerns With The Concept

It is not clear from the submission how broadly the proposed device is to be used, and what situations it will be deployed in. We see no reason why it should not be broadly applicable to barricade functions in general. However, if this is the intention, the specification of a Type III barricade design may not be optimal or appropriate, and may contradict MUTCD practice. The Manual indicates that Type I and Type II barricades are used for channelizing. A Type III barricade is normally used at a point of closure, where a road section is closed to traffic. The Type III barricade is normally not a channelizing device. To the extent that motorists are (consciously or unconsciously) aware of typical applications, this device could be misunderstood if used in a channelizing or hazard marking capacity. It may tell the driver to turn around, rather than to drive around the barricade. This may not prove to be a great problem, because the public so poorly understands the markings and conventions related to barricades. None the less, if intended to be generally used, the design appears inconsistent with MUTCD practice and should be carefully considered. It is not clear why the submitter selected a Type III barricade for this concept, and whether a Type II barricade might not serve as well. It might be that the extra width of a Type III barricade is needed to accommodate the sliding sleeves that cover the arrows.

One limitation inherent in the device concept is that the directional information is limited to some restricted portion of the barricade. This may be contrasted with the current diagonal striping, where the directional information (if it is understood) is inherent in the delineation pattern itself. Thus the marking pattern serves both a conspicuity function and a directional indicator function, and the entire array provides a path cue. With the directional arrow confined to one end of one panel, the detectability and legibility of the directional information will be reduced. This is the trade-off for the better comprehension and flexibility of use in the new concept.

A final concern is that caution must be exercised in the use of arrows in construction area TCD's. Drivers frequently interpret an arrow to mean that a lane change is required. For example, if the proposed device was used on a shoulder closure, approaching drivers would probably be more likely to think that they must move out of the right lane. Thus there may be more unnecessary weaving. An arrow indicator therefore might be less desirable in some situations, or may require additional advance signing to make the appropriate actions clearer.

Unknowns

The visibility of a barricade with the checkerboard pattern shown in the submission, relative to the visibility of the current diagonal striping, is not known. While some experiments have compared different delineation patterns (and demonstrated this could affect visibility), we know of no evaluation of the suggested pattern. Furthermore, since the length of the rail is not specified (4 foot minimum for Type III barricades in MUTCD), the size of the squares is not known. The pattern sketched in the submission shows nine squares per rail. If this is a (minimum) 8" wide rail, this would imply an overall rail length of 72" (6 feet). If this is a (maximum) 12" wide rail, this would imply an overall rail length of 108" (9 feet). It is therefore not clear exactly how we are to interpret the size and patterning of the suggested barricade. Whatever is intended, however, needs to be evaluated for visibility. If lengths up to nine feet are intended, there must also be consideration of problems in application. The device, although a Type III barricade, may be suggested for applications typical of Type I and Type II barricades, which can be as short as two feet in length. Longer barricades may not be appropriate in some applications. Furthermore, where an array of barricades is used as a taper, the initial barricade will occupy a larger portion of the lane, changing the appearance of the taper.

Design Considerations

A primary design consideration is the detectability and legibility of the arrow. The arrow panel section is rather subtly camouflaged within the checkerboard pattern. There is little contrast in size or color. Furthermore, the arrow itself is quite small. Even assuming the maximum rail width of 12", this should be contrasted with the normal size of arrow panels or arrow sign elements for other TCD's shown in Section 6 of the MUTCD (e.g. two-way traffic sign, curve signs, detour signs, large arrow sign, etc.). Given the proposed design, problems may be anticipated in noticing the presence of the arrow and in discriminating its direction.

The device concept actually can be viewed as having two aspects. First, the directional information is removed from the striping pattern, so that the barricade can be flexibly used. Second, less ambiguous directional information is added back in, by means of a simple-to-use attachment. Whatever pattern replaces the diagonal striping must be shown to have adequate detectability and conspicuity, as already discussed. Therefore development of an effective non-directional marking pattern should be considered part of the design work; the proposed pattern may or may not be adequate. Whatever the pattern used, the second design aspect is to develop a directional indicator that is conspicuous, unambiguous, and legible as it is mounted and used on the barricade. As indicated, the specific idea proposed has inherent limitations. It would seem that other means of implementing the general strategy of this concept might be more promising. With the directional information removed from the striping pattern, various means of reintroducing directional information could be considered.

The MUTCD clearly indicates (Section 6C-9) that signs can be erected on or above barricades, and even lists the "large arrow" warning sign as an example. Why not attach folding hinged panels at the sides or top of the barricade? Each panel would show an arrow or chevron pattern pointing in the desired direction. These could certainly provide larger and more prominent directional indicators than the proposed design. Furthermore, if folding "wing" panels were used, the <u>shape</u> of the panel could provide an additional directional cue. Pain, McGee, and Knapp (1981) found that barricade shapes that taper ("point") to one side provide a strong cue to direction.

Furthermore, if the barricade marking pattern is to be reconsidered, it may be worthwhile to consider marking patterns that convey directional information, but can be adapted to more flexible use. For example, Sedney, Walker, Alicandri, and King (1987) considered a "split chevron" pattern. While each barricade panel has a stripe pattern like that of current diagonal striping, the stripes angle in different directions; this forms a chevron shape which conveys a sense of direction. If the frame holding the panels was designed so that the panels could be released (by means of clamps, slots, etc.), the two panels could be reversed to yield a chevron pointing in the opposite direction. Or an X-shaped frame (side view) could be used so that the frame could simply be turned upside down to present the chevron pattern pointing in the opposite direction. These or similar concepts could retain the advantage of the current barricades, which is that directional information is broadly inherent in the pattern itself, and not limited to some smaller feature.

Summary

At its most general level, this concept proposes to take the directional information out of the striping pattern, so that the barricade can be used more flexibly. Directional information is added back in by an inexpensive, easy-to-use flexible feature. At this level of generality, the concept holds promise. However, the specific design suggested has a number of ambiguities, and the directional information will lack prominence and legibility. Alternative means of implementing the general concept should be considered if the idea is pursued. Type II, not Type III, barricades may furthermore prove to be a more effective basis for this concept.

Description of Adopted Design

The adopted design of the direction indicator barricade is shown in Figure H-5. As suggested by the human factors evaluation, a Type II Barricade is used rather than a Type III. Two alternative prototype designs are proposed for testing. One design is similar to the original proposal in that the arrow is shown on the barricade panel. Rather than sliding panels to cover the arrow this movable panel has an arrow on each side and is flipped over to change the directional indication. This allows the use of a larger (12" x 21") arrow, however, if two arrows are needed an addition panel would have to be added to the barricade.

The second prototype design uses a sliding panel that locks into place above the regular barricade panel. Either or both of these panels can be displayed above the barricade panels. The size of this arrow is also 12" by 21".

This barricade will need to be tested to determine driver reaction tot he arrow. The arrows on this barricade are not meant to be used like an arrow panel on detour arrow, but to indicate which side of the barricade is meant for traffic. Field tests should reveal if the arrow encourages unnecessary merging where lanes are not closed.

Standard barricade supports can be used for the direction indicator barricade and are not shown in Figure H-5.

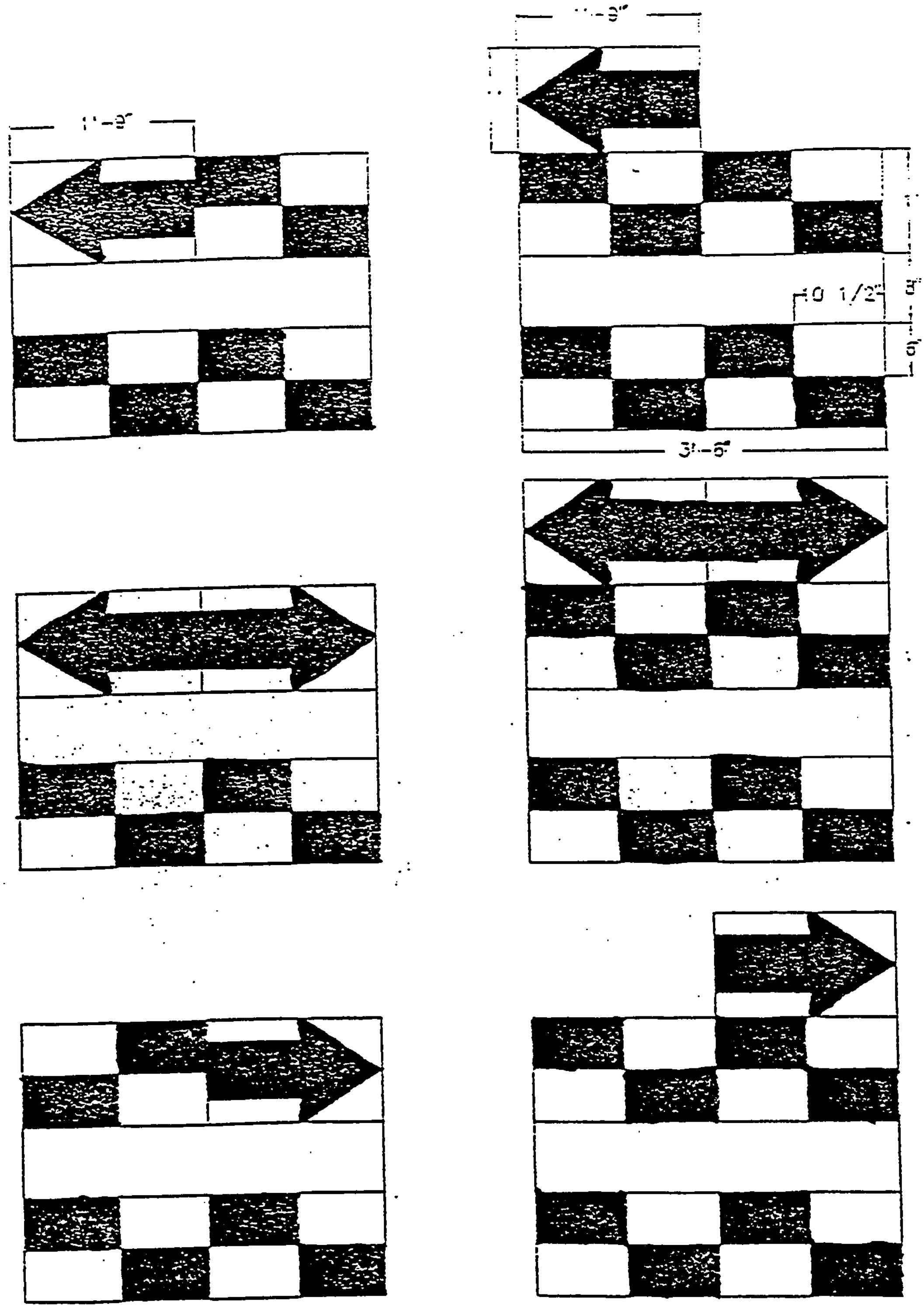


Figure H-5 - Direction Indicator Barricade

Fiber Optic Caltrop

Human Factors Evaluation

Driver Task As Related To The Device

The caltrop is intended to serve as a channelizing device, with a series of the devices arrayed to delineate a path. From the driver's perspective, the caltrop serves the same function as traffic cones or tubular markers. The driver must be able to visually detect the caltrop, and it must have sufficient conspicuity to attract driver attention with adequate time to permit safe maneuvers. Target value must be adequate for all visibility conditions, day and night. Furthermore, the series of caltrops must clearly define a path when viewed as an array.

Benefits

A primary benefit is in the area of deployment. Because the four legs are of identical length, the orientation of the device is irrelevant. It does not have to be "stood" in place, and it cannot be blown or knocked over; it is always "upright." This will make the caltrop easy to deploy from the back of a truck, and does not require personnel to be on the roadway. The stacking feature purportedly makes it easy to store large numbers in a compact manner. By tying the individual caltrops together, deployment is easy and spacing is predetermined.

From the driver's perspective, the device is claimed to have the advantage of high visibility for both day and night operations. Details to support this are not provided, however, and we feel some skepticism, as discussed below.

Problems/Concerns With The Concept

The are several concerns with the basic device concept. The most serious is the adequacy of daytime visibility. The size of the visual target will be discussed later under "Design Considerations." Regardless of size, problems of color contrast and brightness contrast remain. In comparison to the conspicuous orange of cones and tubular markers, the caltrop arm consists of a transparent outer tube, a polished aluminum inner tube, and a layer of optic fibers sandwiched between. This cannot be presumed to be attention getting, and presumably would provide poor contrast with the achromatic surfaces of roadways. It appears that the submitter does not intend for the caltrop to be illuminated during normal daytime use, since a photodetector is included in the device to determine when the bulb should be illuminated. Even if the caltrop is lit during the day, it is not clear how bright or detectable the device would be. Furthermore, if lit for 24 hours a day, and powered to be sufficiently bright for good daytime conspicuity, battery life would necessarily be significantly shorter.

This raises a second concern with the concept. Because each caltrop has its own battery, battery replacement will represent a significant maintenance requirement and continuing cost factor. This is in contrast to cones or tubes. Furthermore, if the battery fails while the device is in use, the caltrop may effectively be invisible at night or in inclement weather.

A final concern with the basic concept is that while the vertically oriented leg of the caltrop will presumably provide the major perceptual cue for the delineated path edge, a base leg of the device could protrude inward toward traffic. For the 15" leg sections described in the submission, the magnitude of this intrusion could approach one foot. This intrusion is greater than for cones, although it may not be particularly serious. However, as will be discussed, the proposed dimensions of the device are quite minimal, and if a larger caltrop is used, the intrusion could be further. For example, if the overall height of the caltrop is made similar to that recommended for another vertical channelizing device, the tubular marker, which is 36" for high speed and nighttime operations, then the extrapolated protrusion of the base leg toward the vehicle path is about a foot-and-a-half. To the extent that drivers use the vertical leg to define the path edge, the intrusion of the base provides an opportunity for minor collisions. These may not be serious but could cause more severe secondary accidents, either through erratic maneuvers by the colliding driver, or through degrading the delineation array.

Unknowns

An initial question faced in this review was whether the fiber optic technology would perform as described. This is a technology issue, rather than a human factors issue, but we felt we could not complete the behavioral evaluation without some further understanding of the performance aspects. We contacted the president of a fiber optic corporation who is highly familiar with the capabilities and uses of fiber optics. He confirmed that fiber optics can be used to diffusely illuminate the device legs in the manner described for the caltrop. Because key design features were not described, the more specific aspects of performance, practicality, and so forth could not be discussed. However, the luminance of the device will be a function of the power supplied, and this in turn will affect cost and battery life. The major point, however, is that general illumination of the arms through fiber optics does appear technically feasible.

Another basic concern is how effectively an array of caltrops would define a path. Unlike a simple solid form such as a cone or tube, the caltrop has four (illuminated) legs projecting at various angles, with one always vertically oriented. As a more complex and spatially extended target, the perspective array of a series of caltrops may lack the simple and immediate clarity of path that an appropriately spaced row of cones could provide. This may not turn out to be a problem in practice, but in principle other channelizing devices may have better target characteristics. The ease with which an approaching driver can visually define the channelized path should be evaluated for this device.

Design Considerations

One set of design issues concerns the effectiveness of the caltrop at night. Of course, target value will be determined in large part by the luminance of the device, and this is simply not known or discussed in the submission. Brightness levels will also represent a trade-off with power demands and maintenance concerns (battery replacement), and this should be considered at the design stage. It should be remembered that the lamp output will be distributed between all four legs of the caltrop. If the bulb or battery or photocell fails, there will be no means for the motorist to detect the device at night. Therefore it is suggested that some reflective band be placed on each leg of the caltrop, similar to that required on cones or tubes. It may be that somewhat less extensive reflectorization may be adequate, since this is a backup and not primary mode, and will limit the area for illuminated display. However, it does seem prudent to provide some backup source of nighttime visibility. Another concern with nighttime performance has to do with the photocell which controls when the lamp goes on. Since the caltrop has no "correct" position, any leg could face up, and the orientation of the photocell will not be fixed. The orientation of the photocell could certainly affect its sensitivity to ambient light, and perhaps the response to more transient sources, such as passing headlights, as well.

The adequacy of daytime visibility has already been addressed concerning color and brightness. Another critical concern is the size of the caltrop. The submission indicates that the typical length of a leg would be 15", which would result in an overall height in a deployed caltrop of 21.5". The diameter of the legs is never addressed. Estimating the dimensions from the proportions of the drawing accompanying the submission, the width of the leg is about 1". These dimensions may be contrasted with cones or tubes. The overall height of cones or tubes must be at least 18", but high speed or nighttime applications require taller devices. The current draft revision to Section 6 of the MUTCD suggests a minimum of 28" for cones and 36" for tubular markers. Even though these devices are wider than the caltrop appears to be (providing greater target area), and have better daytime color contrast, the height of the caltrop is reduced.

It is not clear to what extent the base legs will add to the caltrop's target value. However, the general impression of the caltrop, considering its size, shape, and color, is that it will have limited daytime conspicuity. The design of the device should compensate for this as much as possible. Legs should be wider, although this would increase the surface area over which the fiber optic bundles must be dispersed. Bands of color, or perhaps large orange caps on the tips of the legs, might also help. However, all of these daytime conspicuity improvements would seem to limit nighttime illuminated effectiveness to some degree.

One suggestion to improve daytime conspicuity has been to place some form of material webbing between the legs of the caltrop. This too would tend to block the view of the illuminated upright leg, at least for some viewing orientations, reducing nighttime visibility. However, if the webbing were run only partially up each leg, this problem might be minimized. Also, the use of an open weave in the material, as sometime seen in orange safety vests, might allow some of the light to shine through at night. However, if the webbing does not continue to the ends of the legs, the added daytime conspicuity will be confined to the lower portion of the device, whereas it might be most effective at the upper portion (the end of the leg). Because the limitation of daytime conspicuity is such a critical problem for the caltrop, we believe that the various means of daytime enhancement, singly or in combination, should be formally evaluated. This evaluation must include both the benefits to daytime conspicuity, and the tradeoffs in reduction of nighttime effectiveness.

Related to the visual stimulus characteristics of the caltrop, both day and night, the optimal spacing of devices in a channelizing array needs to be determined. It may not be appropriate to simply adopt the spacing normally used for cones.

Another design consideration concerns the consequences of a vehicle collision with the caltrop. The submission describes the device as "resistant" to breakage, although the thin aluminum legs would appear to be susceptible. However the major concern may be in linking the array of caltrops together with a connecting cable. This is not necessary, but is suggested in the submission as being an aid to deployment and a deterrent to theft. However, if a car collides with a caltrop, the vehicle may become entangled in the cable, and recovery of control by the driver may be more difficult. Furthermore, by moving the cable, the entire array of channelizing devices will become misaligned. For this reason, the design trade-offs between cabling the caltrops or using them independently must be considered.

As a final concern, we mention that several staff members independently thought that this device would be a particularly appealing target for petty thievery. We cannot confirm this objectively, but would warn that there may be delineation problems caused by theft of these devices.

Summary

The practical effectiveness of the fiber optic technology for this application is not clear. It may prove useful for nighttime delineation, but is likely to suffer daytime limitations. Some possibilities for improving daytime conspicuity exist, but are likely to cause some detriment at night, and the magnitude of this detriment in not known. Trade-offs of target value vs. power and maintenance requirements may prove to be a significant consideration. The overall conclusion is that the caltrop, as proposed, will not be effective for daytime use, and the actual visibility and practicality for nighttime use is unclear.

Based on the human factors evaluation, this concept was abandoned.

Opposing Traffic Lane Dividers

Human Factors Evaluation

Driver Task As Related To The Device

The Opposing Lane Dividers are delineation devices designed to be used as center lane dividers to separate opposing traffic when traffic patterns are changed from the normal path. In order for this concept to function effectively, the driver must detect the presence of the devices, and recognize the series of devices as defining a path. The driver must understand the purpose of the delineation array and recognize his vehicle's proper position and path relative to the delineated path. For the particular application proposed for the Opposing Traffic Lane

Divider, the driver must realize that the dividers function as a center line to separate opposing traffic, and that he should remain to the right of the delineators.

Benefits

There are several purported benefits to the proposed device. A major benefit is that the delineator array will be less susceptible to disturbance in an operational setting. If hit by an automobile, the panel section is collapsible, and so avoids being damaged or knocked out of position. Because the panel is spring loaded, it will return to an upright position after being run over. The heavy base should also minimize movement in a collision, and make the device less susceptible to wind gusts. For these reasons, the Opposing Traffic Lane Dividers should improve safety to drivers by making the delineation display more stable and reliable. They should reduce the work of maintenance personnel, and limit the risk of being exposed to traffic when replacing devices.

The Opposing Traffic Lane Divider also provides the driver with more explicit information than does a traffic cone. The panel face provides a location to present a symbolic message, indicating direction or function. The particular image described in the submission is an arrow, but other designs are possible and will be mentioned later. To the extent that the message on the face of the device is understood by drivers, the device can further enhance safety and operations by clarifying the task for the motorist.
The submitter also noted that since Opposing Traffic Lane Dividers are flat when the panels are collapsed, they will be very easily stored.

Problems/Concerns With The Concept

There are concerns about the maintained visibility of the Opposing Traffic Lane Divider under prolonged operational conditions. The device is relatively small (12" wide by 18" high) and low to the ground, and is susceptible to (indeed designed for) being run over. It is therefore exposed to dirt, salt, spray, tire marks, etc. This could limit visibility, and in particular nighttime retroreflective ability. Furthermore, there is the concern that after repeated operation of the spring, due to folding for storage as well as runovers, the sign panel might not return to a fully vertical position. This will reduce the effective visual area of the target. It will also influence the retroreflective response of the surface, since the headlight beam will be more oblique to the surface, and the returned light will decrease as a function of the "entrance angle" of the entering light. A related concern is whether the panel will remain vertical in strong wind. Visual target area and retroreflective effectiveness will be reduced if the spring does not sufficiently resist the wind.

Another concern has to do with the orientation of the devices after collisions. The divider is designed to be relatively stable during collisions, and certainly is much more stable than a traffic cone. However, because the divider presents directional information, and because its target value is dependent upon proper orientation with respect to traffic, the consequences of minor movement can be more serious than for cones. It seems likely that hits by vehicles would typically be toward the outside edge of the device (right side relative to the driver). Collisions therefore might not only collapse the panel, but also have a tendency to displace the device to the left, or rotate it in a counterclockwise manner. Multiple hits over time might lead to a cumulative displacement. This sort of movement might make the device hard to see, especially at night. Thus relative to cones the concept offers greater resistance to the effects of a collision, but its performance may be more sensitive to a given degree of movement. The actual stability of the dividers under operational conditions will have to be evaluated.

A final concern for the device concept has to do with the use of an arrow on the face of the plastic panel. The design is meant to show drivers the intended side of the divider to travel on, and the position the vehicle must assume relative to the device. However, the meaning of an arrow is more ambiguous, and could suffer misinterpretation. Arrows on work zone TCD's tend to convey the message that traffic should move over a lane. Thus the Opposing Traffic Lane Divider could be interpreted as a "merge right" or "lane shift" message, causing unnecessary weaving, or even a movement to a part of the roadway not intended for travel. It is also conceivable, though less likely, that the arrow could be interpreted to indicate a curve, turn, or detour sign, with resulting inappropriate maneuvers or driver expectancies. Some alternative markings for the panel face are discussed under "Design Considerations."

Unknowns

There are no "unknowns" concerning human factors issues of the basic concept.

Design Consideration

One design consideration is the graphic design of the panel face. The panel should provide good conspicuity and path definition, and also can convey directional or operational information. The intent of the arrow on the panel is to indicate where traffic should travel relative to the delineation. As already discussed, however, there may be concerns about using a directional arrow in this application. Various alternatives may be suggested. If it is really desirable to provide the directional information, a chevron pattern may convey this without as much chance of confusion with other arrow-based sign messages. However, the directional indication may not even be the most appropriate message concept. Since the devices are functioning as dividers to separate opposing traffic lanes, an alternative may be to base the panel display on the Two-Way Traffic Sign (W6-3). This message might further clarify the application of the devices and emphasize the hazard of the approaching (undivided) traffic. On the other hand, it might be argued that the most effective design would be to have no graphic image on the panel at all. This would maximize the reflective area of the panel face, to improve conspicuity, particularly at night. Cones used in the same application do not present any additional graphic message, and appear to be well understood as channelizing devices. The various design alternatives ought to be compared, under realistic conditions, in terms of meaning, possible confusions, day and night visibility, graphic legibility, and path clarity. In the absence of such work we would recommend the use of the Two-Way Traffic Sign image as probably being the least likely to engender inappropriate or confused driver actions.

Another set of design considerations address the features which influence conspicuity. The dimensions of the plastic panel are one concern. The submission describes each panel as being 12" wide and 18" high. The 18" height corresponds to the minimum required height for cones, but is less than that recommended for cones used for high speed or nighttime applications (28" in the current draft revision of Section 6 of the MUTCD). On the other hand, however, the area of the panel face, 1.5 square feet, is somewhat larger than the cross-sectional area of even the larger cones (assuming a 28" tall cone with a 12" base and a 2.5" tip, the cross-sectional area is 1.4 square feet). Compared to Type II barricades, however, the target area is restricted. The minimum Type I barricade (8" by 24" rail) has a slightly smaller area, but Type II barricades will provide about double the target area (using only the minimum Type II dimensions, 8" by 24" rails, the area would be 2.67 square feet).

Therefore, at least for nighttime or high speed applications, the suggested device is shorter than alternative delineation devices, and has less visible area than Type II barricades. Compared to traffic cones, however, the device subtends a slightly greater area. If the dimensions were to be increased at all over the submission's 18" height, this difference in target area could be quite substantial (e.g. a 24" inch high by 12" wide panel would provide a 42% increase over the cross-sectional area of the 28" cone). This increased area might be a particular benefit over cones, even under daytime viewing. At night, however, the advantage might be particularly great, since the entire panel face could be retroreflective, vs. the smaller bands of reflective material on cones. While the suggested 18" by 12" dimensions may provide some benefit, it is not clear that these dimensions are optimal, and a taller panel might be desirable for high speed or night use.

Also related to conspicuity, especially at night, is the color, material, and pattern of the panel face. The submission does not actually indicate that the material is retroreflective, although we have assumed this. The device certainly will have increased conspicuity and detection distance if the entire face is retroreflective. The appropriate color is probably orange (although yellow could be used to indicate a centerline). Since orange retroreflective material does not have the brightness of white, it is strongly suggested that areas of white be incorporated into the design. If no (black) graphic message is used on the panels, the pattern could orange and white striping. If a graphic image, such as the arrow, is used on the panel, two other options exist. First, the arrow could be in white, rather than black. This would enhance nighttime conspicuity, but perform less well in daytime. Probably the better alternative would be to provide a white retroreflective border around the sides and top of the panel. The optimal width of this border should be experimentally determined. If a 3" border, analogous to the 3" bands on cones, were used, fully half of the horizontal display area for the graphic image would be eliminated, so some tradeoffs might be required if the panel size remains 12" by 18".

A final design issue really concerns the question of the application of the Opposing Traffic Lane Divider. It is not apparent why the submitter chose to limit the application of this general concept to only the "opposing traffic" situation. Is there any reason why a similar device could not be used for any channelizing function for which traffic cones might be used? The advantage of better survivability in collisions would remain. Directional information might be even <u>more</u> useful and appropriate in other applications, such as tapers for lane closures. If a wider range of applications is considered, this might influence the optimal design characteristics, such as size or graphic image.

Summary

The basic concept does appear to hold promise for improving driver behavior relative to the use of other devices (e.g. cones), in three ways:

1. Because delineator arrays should be more reliably sustained under field conditions, the driver should more consistently get well-delineated path cues;

2. The additional message on the face of the panel may help clarify the task or the hazard for the driver;

3. It may be possible to improve delineator conspicuity, at least relative to cones or tubes, particularly at night.

Despite some remaining design questions, the multiple benefits suggest this concept may be worth pursuing.

Description of Adopted Design

The adopted design of the opposing traffic lane dividers is shown in Figure H-6. The size and composition of the upright panel were taken from the original proposal. The panel is 12" wide by 18" high and is made out of a hard plastic that can withstand being runover. The message or graphic on the panel will probably be varied for the field testing. The two-way traffic symbol is shown in Figure H-6.

The original proposal specified a 3/4" rubberized base, however, the thickness of the base was reduced to 3/8" to make it safer for vehicles that might hit the device. This base would weight about 40 lbs. Field testing will determine the stability of the device with various base designs. For some centerline applications, the base may be glued to the surface.

The hinge pin between the panel and base is surrounded by a coil spring that will return the panel to the upright position after it is run over.

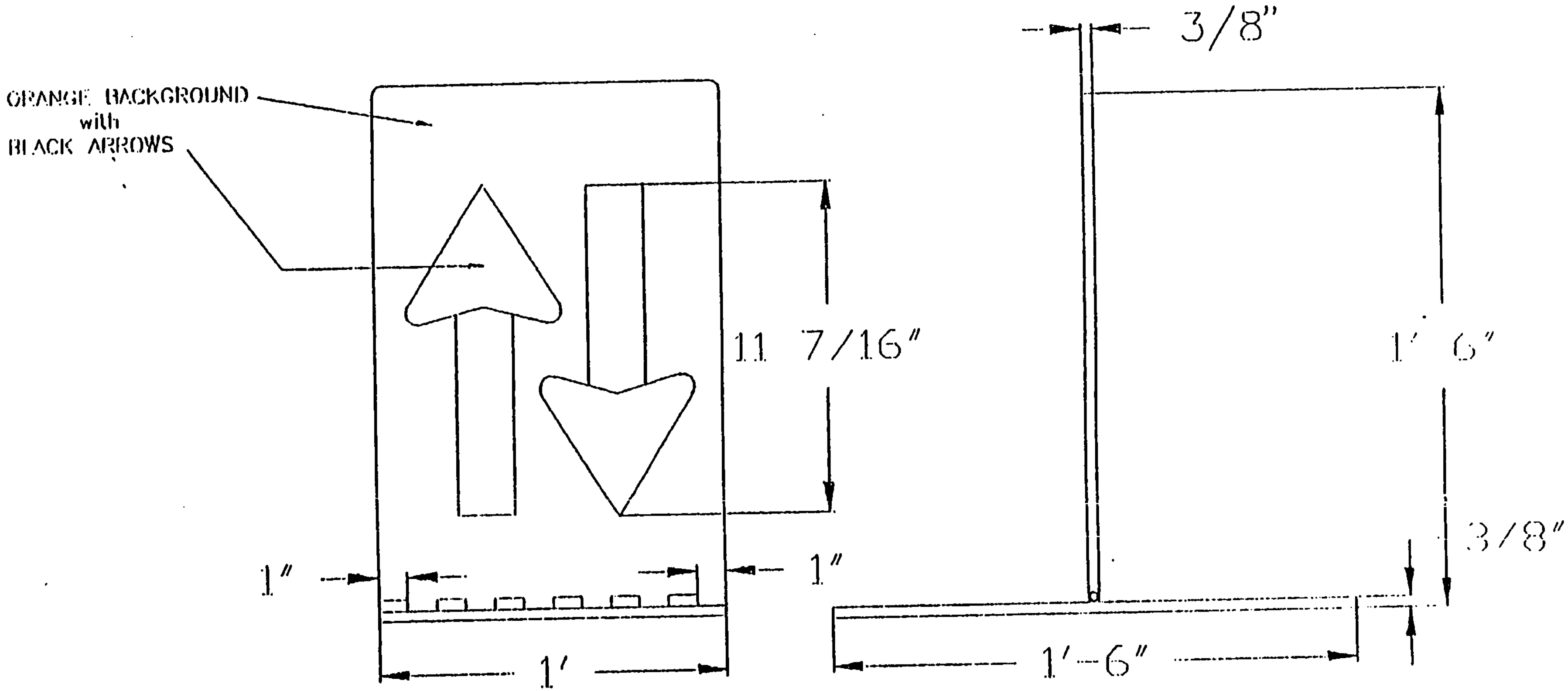


Figure H-6 - Opposing Traffic Lane Divider

Appendix I

Lighting Device Designs

Introduction

Seven device concepts are included in the lighting device study area. Two of the devices are used on snow plows, two devices substitute for flaggers, one is for the rear of maintenance vehicles, one is used to light or draw attention to work zone signs, and one is for use in emergencies.

The Snow Plow Floodlight and Snow Plow Blade Light are designed to both make snow plows more visible and at the same time to make it easier for snow plow drivers to see the path they are plowing.

The TRADER is device that can be used as an alternative to flaggers. This device employs lights that are patterned after traffic signals.

The Diverging Lights is placed on the rear of a maintenance vehicle to make it easier for approaching drivers to judge the speed and distance to the maintenance vehicle.

The Attentive Signing Device is for short term lighting or drawing attention to signs by adding a flare-type light to each sign mounting.

The Police Light Assembly can be used by enforcement agencies to alert and slow drivers approaching an emergency work zone.

The seven tasks in development of lighting devices are shown in Table I-1. Tasks 1 and 2 were be accomplished in Project H-108 and Tasks 3-7 will be done in Project H-109.

In project H-108 human factors studies were done to optimize device designs and to choose methods to measure driver reactions to the devices. The human factors studies investigated the driver tasks related to each device, the expected benefits of the device, problems or concerns, unknowns, design considerations and the overall prospects for behavioral effectiveness. The information contained in the human factors studies led to abandoning of some concepts and modifications to other original proposals. Based on the human factors studies the TRADER, the Teleflagger, the Attentive Signing Device, and the Police Light Assembly were abandoned. The human factors studies of each device are detailed below. Design details are also discussed for all accepted devices. The final prototype designs are presented in this appendix.

In Project H-109 the lighting device prototypes will be built and then tested first on a closed track and then in an open highway environment. Devices that include mounting hardware would also be crash tested (in an abbreviated manner). Implementation packages giving proper use and maintenance will be prepared for successful devices.

Table I-1

Tasks for Lighting Device Testing

Task 1 - Human Factor Studies	Review relevant research and determine lighting device design parameters.
Task 2 - Finalize Device Designs	Based on human factors studies, generate final designs for lighting devices, including supports and mounting
Task 3 - Fabricate Lighting Devices	Construct lighting devices in quantity sufficient for testing.
Task 4 - Test devices in closed track environment	Conduct day and night testing of lighting device in closed track work zone. Eliminate ineffective designs.
Task 5 - Crash Test Mounting Hardware	Test specific mounting hardware.
Task 6 - Tests lights in open Highway Environment	Obtain approval for experimentation and test lights in actual maintenance work zones.
Task 7 - Implementation Package	Prepare guide on use of new Lights in maintenance work zones.

Snow Plow Floodlight

Human Factors Evaluation

Driver Task As Related To The Device

The Snow Plow Floodlight (floodlight) is designed to help motorists detect the presence of a plow vehicle, when the view of that vehicle is obscured by blowing snow and spray. As a driver approaches a snow plow truck, he must become aware of the presence of the truck ahead, and recognize that he his closing on it (i.e. that the truck is moving slowly relative to the motorist). This recognition must come in time for the motorist to safely adjust his speed or path, particularly on a slippery roadway surface. The floodlight is designed to make the presence of the vehicle more detectable and from a greater distance under adverse visibility conditions. The approaching driver must recognize the light as indicating the presence of an obstacle, even if he is not immediately aware that the object is a snow plow truck. The driver must also be able to judge the distance, speed, and closing rate of the truck, in order to plan and execute braking or steering maneuvers.

Benefits

The benefit of the floodlight is its potential to reduce rear end collisions with plow vehicles. These collisions are a common problem in heavy snow for both day and night, with the plow vehicle kicking up spray and snow in addition to the unfavorable atmospheric conditions. This benefit is achieved through enhancing the visibility of the plow vehicle, either directly or indirectly through illuminating the surrounding snow-filled area as the truck moves along the roadway.

Problems/Concerns With The Concept

One problem is that the concept is not very clearly described. The submission describes a yellow floodlight mounted on the hood of the cab, that is "turned to the rear of the truck so as to illuminate the whole rear of the truck." An adjustable shade is used to limit the illumination to the truck body itself, so that following traffic does not suffer glare problems. If this description is taken literally, the concept will have little benefit. The floodlight will illuminate only the upper surface of the truck bed. Unless the following driver's eye position was higher than the truck bed, the illuminated area would not be visible.

Interpreting the submission more liberally, the floodlight could be mounted to the rear of the truck body, on some type of fixture. Then it would point away from following motorists, and would illuminate the rear portion of the truck body. This seems consistent with the submitter's intent. He seems to feel that there is an advantage to the illuminated truck body as a visual target, rather than a directly viewed light source. The logic to this is not clear, unless it is felt that the truck form itself would provide a more concrete cue to headway distance and closing rate. Unfortunately, the illuminated truck body simply cannot achieve the kind of visibility in snowy weather that could be achieved by a warning lamp viewed directly. The effectiveness of the illumination depends on the reflected light from the truck body, and given the snow, soot, and spray of the operating environment, the truck is not likely to effectively reflect the light back to the following traffic.

A third interpretation of this submission is that the floodlight serves essentially as a "traveling streetlight." It illuminates everything within its arc, including the falling snow and the cloud of snow and spray raised by the plow vehicle itself. If this is the intent, then the mounting location described in the submission would be inappropriate. This traveling streetlight concept would seem to be the only interpretation of the submission that has much potential merit.

Whatever the intent of the idea, a serious problem to be faced is that of keeping the floodlight clean. Particularly if the lamp is mounted so as to illuminate the truck body, it will be relatively close to the truck, the ground, and the spray cloud, and it will be facing the spray and dirt kicked up by the plow. The effectiveness of the concept depends on keeping the lamp face relatively clean and transmissive for extended periods in difficult operational environments.

Unknowns

Presuming that the underlying concept is to illuminate the entire area around the truck with a traveling streetlight type of device, the major unknown is quite basic. We do not know what this would actually look like in an operational environment. The idea of illuminating the aerosol and particle "cloud" around the plow vehicle raises difficult questions of optics. The questions of reflection and scatter of light by the various sorts of particles, and the extinction of light as it is transmitted through the atmosphere, need to be determined, and are influenced by many variables. The expert opinion of the staff of the Illumination Engineering Group at the National Institute of Standards and Technology (formerly National Bureau of Standards) was obtained on an informal basis. Their general (and certainly unofficial) position was that the concept seemed "reasonable," but was complex and not easy to assess. At this point, we must consider the visual appearance of the plow vehicle, and the potential effectiveness of the entire concept, as unknown.

If we assume that the floodlight can be effective in illuminating the plow vehicle surround so as to be a conspicuous visual target, there still remain other questions about additional perceptual aspects. We do not know how drivers will perceive the distance, speed, and closing rate of this nebulous target. Even if they recognize the illuminated "cloud" of spray as a hazard, or even as a traveling vehicle ahead, they may suffer misjudgments about its position and movement, with resulting errors in choosing or timing the appropriate maneuver.

Design Considerations

One primary concern is the mounting of the floodlight, in terms of both its location and its orientation. There a several aspects to this concern with mounting. First, the lamp's height, relative to the truck bed and the snow spray, must be determined so that it provides an optimal visual target. Likewise the orientation of the lamp with respect to the vehicle and to following traffic may be important, depending upon the optics of the scatter and reflection of this light. Yet these considerations must be constrained by other mounting concerns. The lamp fixture cannot be mounted so high as to risk damage in low-overhead situations. It must be mounted out of the main area of spray and slush kicked up by the plow, or somehow protected from it, so that the lamp remains clean. Glare remains a potential problem for following traffic, approaching traffic, and for the plow truck driver himself. The lamp must somehow be shaded to prevent direct viewing of the very bright light source for all potential viewers, and this must take into account conditions of grade. It must also account for truck cab mirrors and rear or side windows. For the plow truck driver, who is continually within the illuminated zone, there is yet another concern for night driving. The surrounding brightness could well affect his level of dark adaptation, making the eye less sensitive to traffic or other roadway features outside of the cone of light. The light may also affect his plowing task, depending on its orientation. Conceivably, it could illuminate the area just ahead of him, so that plowing near obstacles such as bridges or curbs could be aided. On the other hand, the light could be positioned so that it throws these obstacles into shadow (from the truck cab or plow blade), making positioning of the plow blade more difficult. Thus in summary, there are quite a few important design considerations for placement of the light which must be incorporated into the design of the floodlight.

Another design consideration is the color of the lamp. The submission suggests yellow, which may be reasonable in terms of the meaning it conveys. Again, however, the optics of transmitted light through the complex atmospheric conditions must be considered. Different wavelengths of light are differentially reflected, scattered, and extinguished by the variously sized particles in the atmosphere. The optics of the situation must be taken into account in order to assure a visually effective target for approaching vehicles.

Summary

The actual appearance of this device, if the concept were implemented, is too poorly understood to permit any judgment of its perceptual effectiveness. The idea of the "traveling streetlight" is an interesting approach that might prove feasible, but needs to be evaluated as an optics problem.

Description of Adopted Design

A problem arises with trying to find a light that will pierce a snow cloud made by a snow plow. The Minnesota Department of Transportation (MN DOT) has ben working on both lighting and plow blade design to overcome or reduce the snow cloud problem. Their experience shows that any light can be obliterated by a snow cloud.

The MN DOT had not experimented with a floodlight above the snow plow that shine down on the bed. The floodlight can be mounted either on the front or the rear of the dump bed. Figure I-1 shows an example mounting scheme. Experiments will be conducted to determine the optimum location, mounting height, number of

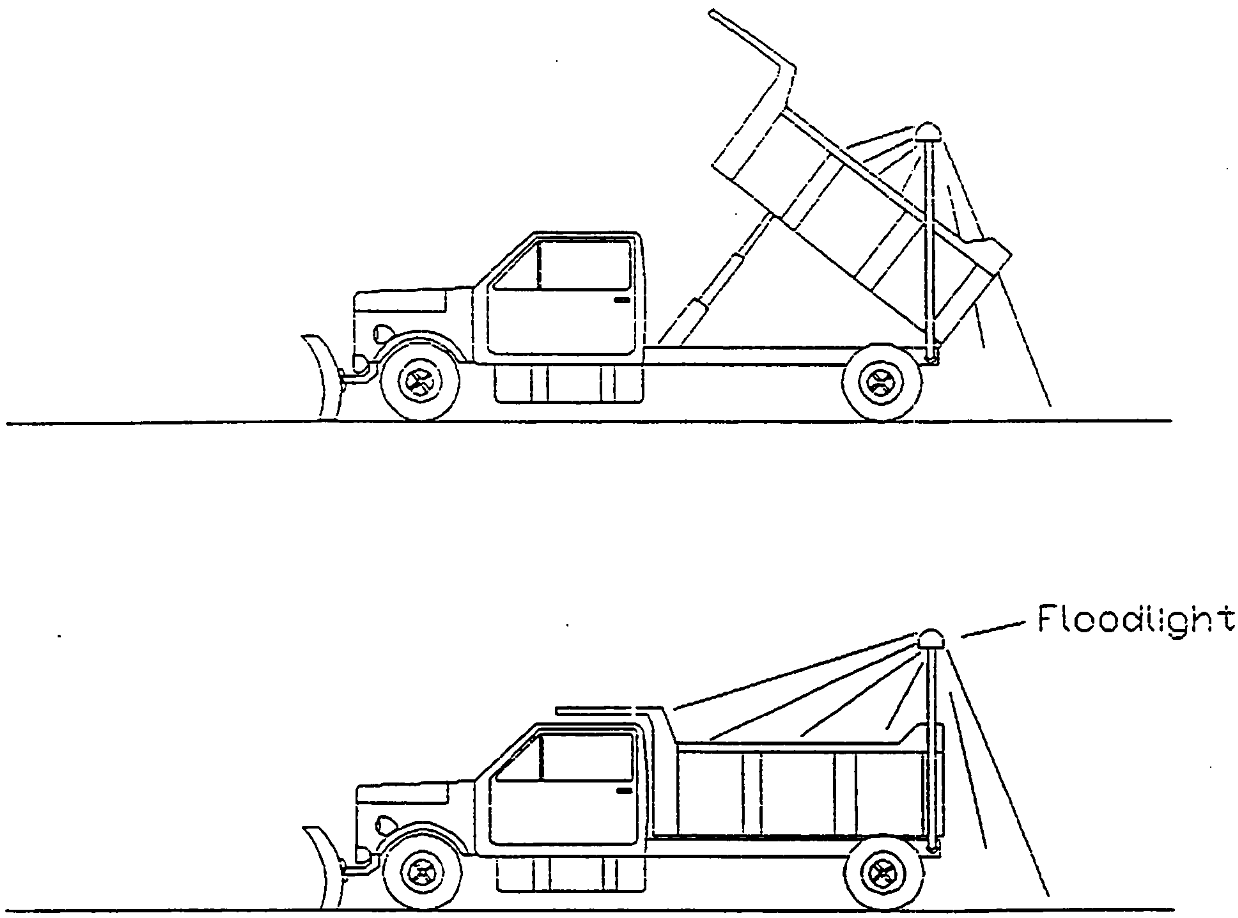


Figure I-1 - Snow Plow FloodLights

lights, color and required shading (to keep the light from blinding the plow operator and driver). The goal is to develop a light that will illuminate the plow as it drives down the highway.

The light will shine down on the bed of the plow no matter what position the bed is in. The light and mounting hardware are always in the vertical position.

Ideally, the height of the floodlight should be above the snow cloud to keep from being obliterated. However, it can not be so high as to hit bridges and other overhead structures.

The number and type of lights will be determined. The MN DOT has been working with a lighting manufacturer to improve their lighting system. The same approach will be taken with the floodlights. We will rely heavily on the experience of highway agencies and lighting manufacturers to develop the optimum system.

Yellow is the preferred color at this time. Most rear end snow plow accidents occur during daylight hours. Yellow lights are best for daylight operations. Blue strobe lights are the best for piercing snow clouds at night. It may be that a combination of different colored lights will be developed.

The floodlight will require some type of shading or special lens design to keep the bright lights from blinding plow operators and drivers. The light should only illuminate the dump bed.

Another problem is with the splash and spray that is thrown off of the truck's wheels when the snow is wet. Lights covered with dirt and grime become obliterated and must be cleaned regularly so that they can be seen by motorists. The optimum mounting location will be determined.

Work will first be done to develop the best lights, mounting hardware and electronic components before the floodlights are tested in actual snow removal operations. The midwest States of Missouri, Iowa, Nebraska, and Minnesota are prime candidates for test sites. The initial testing will be done in one or more of these States. If necessary, other States will be utilized to test the advanced, refined versions of the floodlights. Other snow conditions such as those around the Great Lakes or Western mountains will be considered.

Snow Plow Blade Markers

Human Factors Evaluation

Driver Task As Related To The Device

For drivers of vehicles overtaking the plow truck, the snow plow blade is a collision hazard that they may fail to recognize, particularly under limited visibility conditions. The intent of the proposed marker lights is to indicate the presence and extent of the blade. For this to be effective, the driver must detect the light, comprehend its significance (as an object marker), and properly judge its distance, all at a sufficient distance and time so that inappropriate maneuvers can be avoided or evasive actions taken.

The marker lights are also intended to facilitate the task of the plow operator. They help to perceptually define the spatial limits of the plow blade, relative to roadside features and obstructions (e.g. bridges). For this perceptual function to be effective, the light must be clearly visible from the normal driving position, and its location in space should be accurately perceived.

Benefits

The blade markers have the potential to reduce two sorts of collisions with other vehicles: (1) where the plow blade drifts over the lane line, or another vehicle crosses the lane line, with resultant contact; (2) where a passing vehicle overtakes the plow truck and then cuts in front of it, not realizing there is a blade extending forward from the truck. In addition to reducing the likelihood of these sorts of accidents, the light markers have the additional potential benefit of reducing snow plow blade damage that occurs as a result of operator misperceptions of blade location.

It should be made explicit that the proposed device does not attempt to enhance the visibility of the plow truck itself. It is designed to make the existence and spatial extent of the plow blade more obvious.

Problems/Concerns With The Concept

As the device is shown in the proposal, it will not serve as a well-defined visual stimulus for a viewer. Particularly at night or in inclement weather, the single, isolated lamp is likely to appear as an ambiguous point floating in space. It will be difficult to integrate perceptually into the visual scene. It may not be readily seen as a part or extension of the plow truck, and its size and distance will be difficult to judge. If the surrounding visual cues are minimal, features such as intensity or color can also influence distance judgments. Some possible design features to address these concerns will be discussed below.

An important concern, not addressed by the submission, is how the lamp will be kept clean. Snow plows will operate in bad weather on snowy or wet roads, and the blade itself may raise snow, slush, spray, and salt or sand. Therefore the lamp should be expected to be dirty and/or encrusted with snow and ice. This will significantly degrade the visibility of the light. This would appear to be a rather fundamental problem, and needs to be somehow addressed by the design or placement of the lamps.

There seems to be an implication in the submission that the blade markers will be effective for daytime conspicuity. The lights should provide good nighttime conspicuity, but may contribute relatively little in daytime. If they were bright enough to be readily detectable under all daytime conditions, there may be glare and annoyance problems at night, particularly for the plow truck driver who will have them continuously displayed not far in front of him. A dimming feature could be included to permit brighter daytime levels. However, flags may remain more effective for daytime use, with the lights seen as supplements for daytime effectiveness, but primarily intended for use at dusk or dark or other limited visibility conditions.

Unknowns

We do not know what the typical spray pattern around snow plow blades would look like. This pattern may determine the feasibility of the concept, or at the least might influence the placement of the lamps. The spray pattern could influence the visibility of the light both through dirtying the lamp and through creation of an obscuring haze between the light source and the viewer.

Design Considerations

The blade marker should be conspicuous, recognizable, and readily judged. It should not be confusable with other light sources, such as vehicle brake lights. These considerations will influence the design of the device in terms of configuration, color, brightness, location, and temporal mode.

We would recommend the use of a steady amber lamp. The steady light is preferred to a flashing mode because the correlation of the movement of the light with the movement of the plow vehicle will be more apparent, so that it will be perceptually integrated as part of the truck. Furthermore, a steady source will probably provide a more usable spatial cue for the plow operator, and will not engender the annoyance that a continuously flashing lamp in the near field might cause. Amber is an appropriate color because of its "caution" connotation and because it is used on vehicles. Red could be misinterpreted as a brake lamp under limited visibility conditions. Furthermore, due to a phenomenon called "chromostereopsis", differential refraction by the eye of different wave lengths of light causes a red light in a poorly defined field to appear farther away than other lights. This could result in errors of judged distance which could contribute to an accident.

In terms of the blade marker configuration, an improved design would use an array of several lamps (e.g. a vertical arrangement of three lights), rather than a single lamp. This is because the array would be more readily seen by approaching drivers as a moving object, rather than as an undefined point floating in space.

It would also provide a more concrete distance cue, particularly for the plow operator who is using it to judge plow position relative to obstacles. The spacing and alignment of the lamps would provide more accurate cues to distance and position relative to the viewer.

The brightness of the lamps should be limited by any problems that they could cause the plow operator. The lamps should not constitute a source of glare or annoyance.

The positioning of the lamps should take into account the spray pattern generated by the plow blade, as mentioned previously. Assuming compatibility with this requirement, the mounting height of the blade marker should be at least at normal passenger vehicle driver eye height. Laterally, the placement should be at, or just beyond, the outer edge of the plow blade, since this is the location of critical importance to both approaching drivers and the plow operator. Some consideration should also be given to the longitudinal placement of the lights.

As illustrated in the submission, they are mounted at the rear of the plow blade. This probably makes sense in terms of ease of mounting and ruggedness. However, the leading edge of the blade may be more critical for both operator judgments of obstacle avoidance and maneuvering decisions of overtaking drivers. It should be recognized that the plow operator will be viewing the outer blade edge from an angle, and to the extent the blade marker is displaced backward from the front of the blade, the use of the light position as an accurate cue to blade position is made more complex. It may be possible to project the lamp assembly forward toward the front of the blade; however, the caution about minimizing the effects of dirt and spray must be kept in mind.

Summary

If the device can be kept clean and visible under operational conditions, it should prove beneficial to both the plow operator and interacting traffic. However, this may not be trivial. Design features are needed to provide a visual stimulus that is perceptually interpretable.

Description of Adopted Design

The snow plow blade light had been tested by the Minnesota DOT (MN DOT) on their wing plow blades. With the wing plow in the raised position, the light was effective as a delineator to make passing motorists aware of the wing plow.

Plow blades take a physical beating when on the road plowing snow. The vibration is transmitted up the shaft of snow plow blade light. MN DOT had problems with the shaft breaking because of vibration. They also had trouble with the lights mounted on top of the shaft burning out because light bulb filaments broke because of vibration.

The design to be tested will utilize fiber optic technology as the light source. Figure I-2 shows the lights mounted on the plow blade. The light will be illuminated at the top, middle and bottom of the shaft to show that the light is attached to the plow blade and not floating in space. The light will be steady-burning to serve as a delineator and not as a warning light. Yellow is the preferred color for the light, but blue will be evaluated also.

The housing shaft for the light will be a light-weight material, 12- to 24 inches in length, that can absorb jolting and vibration such as a soft plastic or rubber. The point where the housing is attached to the plow blade will be flexible or rubber-mounted to also absorb vibration.

The snow plow blade lights will be tested during the day and night during snow removal with winter road conditions. Tests will evaluate the lights to determine the weather and road conditions that affect the visibility and operation of the lights. Data to be collected includes detection distance, visibility, vehicle speeds, driver reaction, directionality of lights, durability, and service life.

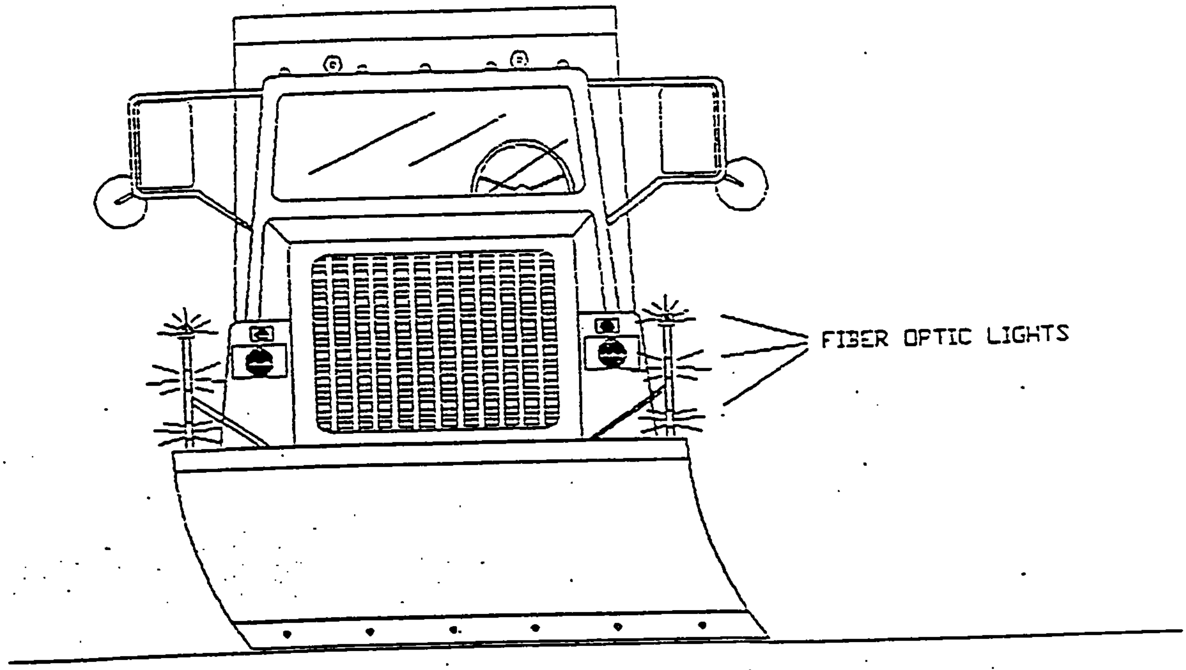


Figure I-2 - Snow Plow Blade Lights

Snow plowing operations will be videotaped from behind the plow, along side while passing the plow, and approaching the plow from the opposite direction. The lights will also be videotaped from inside the cab to get the snow plow driver's perspective.

Durability tests will be done by leaving the lights mounted on the plow blade for an extended period of time to determine the long-term effects of jolting and vibration.

Plow operators will also be interviewed to get their evaluations of the lights including benefits to plowing operations and problems with visibility or motorists.

TROTAR (Transportable Remotely Operated Traffic Advance Regulator)

Human Factors Evaluation

Driver Task As Related To The Device

The proposed device is a type of "hybrid" between a normal traffic signal and a flagger. As with any traffic signal, the driver must detect and recognize the signal, understand its meaning, and make a judgment about the appropriate maneuver and speed based on the signal phase and the driver's position and closing rate. A flagger also serves to indicate to the driver whether a stop maneuver is required, but in addition conveys the further information that there is a work area ahead and that caution may be required. The presence of a work area carries the implication that there may be unexpected hazards (objects, work crew, lane changes, conflicting traffic) that the driver familiar with the roadway would not otherwise anticipate. Thus while both the traffic signal and the flagger indicate the appropriate maneuver at the point of the TCD, the flagger also indicates the need for caution in the area beyond the TCD itself.

Therefore the TROTAR must also convey the information that the device demarcates the beginning of a work zone.

Benefits

There are presumed benefits to the device for both work crews and the driving public. The primary benefit to workers is that the flagger is physically removed from proximity to traffic. The human controller operates the signaling device remotely, providing greater personal safety. The advantage to drivers is that the device, being based on a traffic signal, is familiar in its meaning, and the proper response to its various phases is unambiguous. This is in contrast to human flaggers, who may use various inconsistent techniques, the meaning of which may not be clear to some drivers.

Problems/Concerns With The Concept

This concept takes advantage of the common traffic signal as a well-understood TCD with a generally high degree of motorist respect and compliance. However, because of the familiarity with traffic signals, drivers will have certain expectancies about the situations in which they encounter traffic signals. These expectancies may be violated by the TROTAR application, with the potential for confusion and accidents.

First, the traffic signal normally controls traffic at a point of potential vehicular conflict. Beyond this point (typically an intersection), there is no continued hazard. In contrast, the hazard in a work zone is not particularly severe at the point of the flagger, but more so downstream of this. Thus the TROTAR may not foster the desired slowing and caution as a driver proceeds beyond the device and through the work area. Nothing about the device, except for the small message panels next to the lights, gives any indication that this is a work zone with a continuing need for caution. Presumably there will be some advanced warning signs, which would help. But the TROTAR itself does not indicate the hazard, and in fact, the similarity to the traffic signal might suggest that it is safe beyond that point.

A traffic signal also normally provides a steady yellow phase to clear the intersection, and to reduce the decision conflict of drivers who are too near the signal to stop safely if it were to turn red. TROTAR apparently does not provide this. The green phase is only a brief event used to initiate traffic movement; after this, the yellow light remains on. Although unstated, this presumably means a flashing yellow. However, here again there may be a conflict with driver expectancy: the flashing yellow mode is not used as part of a signal sequence, so that the driver will not be anticipating any need to stop. The MUTCD (4B- 18) indicates that when there is an automatic change from flashing mode to stop-and-go, the change should be made at the beginning of the major street green interval (thus precluding a transition from flashing yellow to red). The TROTAR might try to mitigate this problem by including a steady yellow phase (between the flashing yellow and the red phases), but this may not be particularly conspicuous to the driver. The main point here, however, is that the approaching driver will not be anticipating a likely need to stop, and the transition from flashing yellow to steady red may cause confusion, erratic maneuvers, or attempts to "run" the signal.

Another expectancy drivers may have is that traffic signals do not provide roadway obstacles. They are in a fixed position off the road. In contrast, the TROTAR can move into and out of the roadway. An approaching driver who sees the (red phase) TROTAR in his lane may assume that his proper position should be to the left of the signal; this could bring him into conflict with approaching traffic. Drivers approaching as the TROTAR begins a red phase also may have problems. It is not clear from the submission exactly how the sequence of signals and TROTAR movement will take place. Will the signal turn red before the TROTAR begins to move into the roadway, at the same time movement begins, or after the device is in the roadway? In any of these cases, there can be problems. If the driver sees a red signal and begins to stop, there is no stop line to indicate the appropriate stop position (which drivers may not normally take seriously anyway). If the driver stops at a point too near the TROTAR, he may be in its path as it continues to move into the roadway.

The exaggerated size of the TROTAR signal lenses, combined with the relatively low mounting height of the display, may also cause problems. The MUTCD indicates that the <u>bottom</u> of the housing of a signal face should not be less than 8 feet above the pavement; in contrast, the lower signal lens on TROTAR is perhaps 2 feet above the ground, and the top of the display is about 8 feet high. Because of this, advance visibility, especially if there is intervening traffic, may not be good. The signal may seem to appear suddenly, and given the large (24 inch diameter, vs. normal 8 or 12 inch lenses) signal lens, the driver may suffer the illusion that he is much closer to the signal than is actually the case. This could cause sudden braking or erratic maneuvers, with rear-end or other collision risks.

Unknowns

There are no unknowns regarding human factors issues of the basic concept.

Design Considerations

There are a variety of design considerations for human factors aspects of the TROTAR. To begin, there are several concerns with the signal display. The proposed display consists of red, yellow, and green lenses, two feet in diameter, plus a message panel (about 2.5 by 1.0 feet as estimated from the drawing) next to each signal ball.

The message panels do not appear to be useful. The very advantage of using a device based on the traffic signal concept is that people comprehend the meaning of the indicators. So for example, a message next to the red light that reads "STOP. WAIT FOR GREEN" is unnecessary. Furthermore, the small size of the message panel limits its legibility; given the 12 inch panel height, with two lines of text plus margins, the letter height might be expected to be only about 4 inches. Therefore the message panels could not provide good advance information that would aid the driver. If there is any virtue to having a message panel, it might be in clarifying that the signal indicates the beginning of a work zone, with workers, vehicles, or objects ahead. However, this is done only very weakly by the suggested messages. Both the yellow and green indications include the message "Watch for Worker." Besides the poor legibility and conspicuity of this text, it is not a very powerful message and its meaning may not be clear if the driver does not appreciate the work zone context. We would therefore recommend that the message panels be eliminated. If desired, they could be replaced by a more effective indication of a work zone. This could be through fixed signing, a single large message panel, or even orange and white striping. As the message panels stand in the submission, however, they accomplish very little.

The signal lens size is proposed as 24 inches in diameter. This is two to three times the size of typical signal lenses and hazard identification beacons. The reason for the extreme size is not clearly indicated, but apparently is for enhanced visibility, since the submission states that "the huge light board is easily seen from a long distance in even adverse weather." However, the major limitation to good visibility distance for this device is its mounting height. Even ignoring the green lens, the critical yellow and red lenses will be between about 4 and 7 feet above the ground. This could easily lead to obscuration by intervening vehicles, brush, or minor vertical curves. The larger lens size will not compensate for this limitation. It is also not clear whether these large signals are available products, and what their luminance would be. There is no apparent reason to presume that a normal 12" lens is inadequate, since the visibility concerns for the TROTAR signal are not unlike those for any other signal on higher-speed roads or for problem intersections. The really critical concern is that whatever the lens size, the driver's view of it may be obscured under certain conditions. The TROTAR design should reconsider the mounting height of the signals, even if it means a smaller lens face. It might be that the submitter chose this low mounting position as being more analogous to the position of a flagger's paddle, and as presenting a more obvious target, in the driver's line of sight, when the TROTAR is positioned in the roadway itself. However this could be addressed by having the lower portion of the TROTAR made highly conspicuous (striping, lighting, or even a second smaller set of lens faces), and still mounting the primary signal head high enough to provide acceptable sight distance. The submitter sees TROTAR as a sort of robotic flagger, but this analogy should not be taken to imply that positioning the display where a flagger paddle would appear is necessarily the optimal position. Furthermore, good sight distance will be more critical for TROTAR than it would be with a human flagger. This is because a flagger will frequently have more flexibility in positioning himself. The ideal location will give the flagger a clear view of approaching traffic, and provide approaching traffic a clear view of the flagger. The viewing position of the flagger is the same as the physical location of the flagging device (his paddle or flag). In contrast, TROTAR is controlled by a remote observer who must monitor two TROTAR units, one in each direction. He therefore has much less flexibility in locating the devices, particularly with respect to maximizing their visibility for on-coming traffic. To take an example, assume that traffic is approaching up a grade, with the work zone somewhere beyond the crest. A flagger could position himself at the crest, where he could view approaching traffic, and also observe the work area, and also be visible to the approaching drivers. This may be contrasted with the situation for the individual who must control traffic from both directions using two TROTAR units. If a single observer cannot see vehicles beyond the crest, the TROTAR unit will have to be moved sufficiently back from the crest so that the controller can have some view of the traffic approaching it. However, this means that the approaching vehicles will not have a clear view of the TROTAR, since it is beyond the crest. This scenario is simply described in order to illustrate that there can be situations of many sorts for which the driver's sight distance to a TROTAR will not be ideal, and so a significantly higher signal display, consistent with other traffic signals, is desirable.

One critical aspect of the design concerns the transition from the "go" phase (yellow) to the "stop" phase (red). The TROTAR moves into the roadway for the red period. What is not clear is when this movement begins, and how rapidly the TROTAR moves. It would seem best to provide the driver with some cue that the signal is changing and/or the TROTAR is about to move, so that he can be prepared for the intrusion of an object into the roadway. Thus it would seem that the change from yellow to red should precede movement into the roadway. If there is no display change in advance of movement, the driver may not detect the imminent hazard and would have no reason to slow down since the signal was not red. Once the TROTAR begins to move into the roadway, the speed of this movement will be important. If it is too fast, there is the chance of a collision. If it moves too slowly, drivers may fail to notice the movement, and perhaps more importantly, there will be a tendency for some drivers to try to "beat" the barrier in the same way that drivers try to beat a railroad crossing gate. It might be useful to append some flexible barrier or indicator to the roadway side of the TROTAR, so that there is an obvious in-the-roadway indicator before there is a solid object which provides a collision risk. For example, even a flag on the end of a flexible arm could precede the TROTAR while it is moving into position. This would appear to provide an extra level of safety in reducing collisions with the TROTAR.

The speed of movement of the TROTAR on its track drive also relates to the issue of control by the human flagger. Unless it can move rapidly, the human controller cannot react to individual vehicles that may not be responding properly, and collision avoidance will be more difficult. If TROTAR is capable of rapid speed, there may be other problems of moving too quickly into the path of an approaching vehicle. Certainly the design of the remote control should preclude accidental movement of the TROTAR and high-speed maneuvering should require deliberate actions.

Another serious concern has to do with the durability of the TROTAR in the field and the ability of the on-site work crew to conduct any maintenance or repair. The device is a complex collection of mechanical systems, remote signaling capabilities, computerization, hydraulics, lighting systems, and associated power supplies. Problems with any of these components could make the system ineffective. The design of the TROTAR should include ease of repair by the flagger, but one must be skeptical of whether this can be easily accomplished.

Another concern about maintained performance is the effect of a vehicle collision with the TROTAR. Even if the collision is at low speed, at least two signal faces are likely to be broken. It would also seem likely that the track drive mechanism could be damaged. Since some low-speed collisions ought to be anticipated, the TROTAR should be designed to withstand such events.

This also raises the concern over the severity of the outcomes of vehicle collisions with the TROTAR. The concept essentially means regularly moving a large, heavy object into the traveled roadway. The submission addresses this concern in an ambiguous manner, by indicating that "a foldable crash attenuator could be mounted on the back." It is not apparent how this would work. Certainly a crash attenuator could not be fixed in place on the ground behind the device, since the TROTAR moves laterally into the roadway itself. If the attenuator is mounted on the rear of the TROTAR itself, it is not apparent what it would be cushioning against.

Summary

TROTAR is unusual in presenting a TCD similar to one (traffic signal) that is highly familiar to drivers, but which violates certain expectancies drivers have about traffic signals. There are also serious concerns about the adequacy of the visual display. Given these concerns, and the fact that the device itself might present a collision hazard, this would appear to be a relatively high-risk concept. The idea of being able to position the controlling device in the roadway itself has some advantages, but other approaches, such as the Flagger Gate, may accomplish this more safely.

Based on the human factors evaluation and the risk of collision, the TROTAR concept was abandoned.

Diverging Lights

Human Factors Evaluation

Driver Task As Related To The Device

The "Diverging Lights" are mounted on the rear of a slow-moving maintenance vehicle. They are intended to provide a visual cue to a following driver that he is closing with the maintenance vehicle ahead. Actually, because it exaggerates any real cues about headway (e.g. the increase in the visual angle between the tail lights), the device may be said to induce an illusion of greater-than-actual closing rate.

The approaching driver must detect the presence of the diverging lights and attend to them; this is a function of visibility and conspicuity. He must then recognize that this device indicates the presence of a vehicle, or at least that it indicates some potential obstruction ahead. The driver must appreciate that he is closing on the vehicle, i.e. that it is moving slowly relative to him. He must recognize the position of the maintenance vehicle relative to his own (e.g. same lane or different lane), determine whether some altered course is required, and if so, what the appropriate maneuver is. He must also estimate the closing rate and the time available for any maneuvers; to the extent that the driver overestimates the available time, there is a risk of collision or erratic maneuver.

Benefits

The brief synopsis of the concept indicates that the device is "designed to improve a driver's judgment of the speed of a maintenance vehicle and the closing rate with these vehicles." Actually, an "improvement" may not always be the case, and the more precise statement might be to say that the diverging lights can serve to <u>bias</u> distance and closing rate judgments in the direction of reducing apparent headway. This should make drivers more conservative in the choice of speed, headway, and lane change maneuvers, with the resulting benefit of fewer rear end collisions.

The Diverging Lights might have other benefits as well. There may be some conspicuity enhancement, relative to no additional lights. This would improve the probability and speed with which approaching motorists become aware of the "object" ahead. Also, the lamp pattern might help clarify the spatial extent (width) of the hazard; this will only be true if the position of the outer lamps corresponds to the sides of the vehicle.

Problems/Concerns With The Concept

While the concept of providing "closing rate" cues to approaching drivers is intriguing, there are some tradeoffs versus other delineation functions. The first concern is with the conspicuity of the display. The values of the <u>optimal</u> display parameters are likely to be different for the illusion of rapid headway reduction than for simple conspicuity. For example, the flash rate, and the duration (if any) of a dark period between successive lamp illuminations, can be optimized for either conspicuity or perceived closing rate, but probably not both simultaneously. This will be discussed further under "Design Considerations." Aside from the parameters chosen, however, the Diverging Lights must be compared with alternative truck-mounted TCD's. Compared to an arrow panel (towed or truck mounted), the proposed device, with only two lamps visible at a time, will not be as conspicuous. For daytime applications, it is not even clear how the conspicuity of this device would compare with truck-mounted passive signs (with or without a flashing vehicle light as well), which offer a much greater target area. The diverging lights could conceivably be used in conjunction with other high-conspicuity TCD's, but this could prove confusing to drivers, particularly at night. Furthermore, to the extent that the Diverging Lights are used in combination with other high-conspicuity displays that do <u>not</u> expand in size, the illusion of rapid approach will be weakened or destroyed. This incompatibility is probably more significant for some TCD's than others. For example, an arrow board would be incompatible and provide a clearly contradictory cue as to closing rate; but a flashing yellow lamp mounted on the top of the maintenance vehicle would not provide as concrete a cue to distance, and would be more compatible. In any case, the adequacy of the maintenance vehicle's conspicuity, whether the Diverging Lights are used alone or in conjunction with other TCD's, must be determined.

The ability of the Diverging Lights to command attention is also important because if the driver's attention is not drawn to the light display, it cannot exert its full influence on the perceived closing rate. Therefore conspicuity as a characteristic of the display should not be treated lightly.

Another concern is that the device does not convey any explicit information about required maneuvers. Blinking lights, by themselves, are ambiguous to drivers and do not strongly convey a message of the need to change lanes. This is in contrast to arrows, chevrons, and sequential arrows, which strongly imply lane closure to the approaching driver. Likewise truck-mounted fixed signs or variable message signs can indicate a specific hazard (e.g. "one lane road ahead") or required maneuver (e.g. "lane closed, merge left"). Thus even if the driver detects the flashing lights of the proposed device, this may not adequately convey a sense of hazard, and may not indicate that a lane change is required.

Unknowns

There are no "unknowns" concerning human factors issues of the basic concept.

Design Considerations

The are numerous parameters that must be considered in the design of the Diverging Lights concept. These include the lamp configuration (pattern), duty cycle aspects (on time for each lamp, off time between successive lamps, blank time between sequences), size of the lamps, changes in lamp size, spacing between lamps, brightness, etc. These parameters have implications for the induced perception of "closing" with the device, as well as for other aspects such as conspicuity and appropriate maneuvers.

Studies of human perception and movement have indicated that the major visual cue to the approach rate to an object is "looming," or the expansion of the retinal image of the target. For vehicle drivers, in particular, the primary cues to closing rate appear to be changes in the visual angle subtended by the target, and the rate of this change. At night, from a distance, the degree of separation between tail lights will be the most important factor, as the lights are essentially point sources and other visual information is not visible. However, under better visibility conditions, or when close enough so that the lamps themselves have visible dimension, the expansion of the entire visual array is important. This has implications for the design of the diverging lights. For distant, night viewing, the increasing spatial separation of the lamps may be effective in inducing the perception of a faster rate of approach; but under daytime, well illuminated, or nearer viewing conditions, the aspect of the rear of the maintenance vehicle itself provides a contradictory set of cues, and the fact that the individual lamps of the diverging lights do not also expand in size (loom) is contrary to the illusion.

In order to induce a stronger illusion of rapid closure, the ideal features of the light display should correspond to the actual optical changes associated with "approach." This means that all aspects of the display should expand, and should expand at the same rate. For example if the distance between successive lamps increases by 50%, the diameter of the lamps should also increase by 50%. Similarly, the rate of increase from one phase of the display to the next should correspond to the way in which retinal images expand as the target is approached.

This expansion is not linear. Rather, the rate of growth is hyperbolic, increasing as the target is approached. Thus to realistically simulate visual looming, the sequence of three displays should grow more from the second to the third phase than it did from the first to the second phase.

In order to clarify this, some figures are attached. The Table I-2 and Figure I-3 illustrating the changing visual angles subtended by an approaching train are taken from Mortimer (1988), and serve to show how the change in visual size (angle in degrees) over a given distance is larger when that distance is closer. The Figure I-4, taken from Sekuler and Blake (1985), shows the expansion of the retinal image over time as a one centimeter target is approached from 100 meters away. The two curves show two different rates of approach (1 meter/second vs. 5 meters/second). These examples show that the rate of growth increases as the target is neared. Therefore increasing the rate of change of expansion in the Diverging Lights pattern should enhance the illusion of approach.

What is the "correct" rate of expansion if one is trying to simulate reality? That depends on the presumed separation distance and closing speed of the two vehicles. As the figure just referred to illustrates, that change in retinal image size depends on both approach speed and distance. Therefore there is no generally "correct" rate of growth. Furthermore, the most "realistic" rate of growth may not necessarily be the best to use for the Diverging Lights application. Some exaggeration of reality may be helpful, as long as it is not so extreme as to destroy the illusion. Some testing of human perceptual responses to the lamp display would be required to objectively identify the optimal image growth rates.

Table I-2

Angle Subtended at Eyes of Motorist by the
Front of a Locomotive at Various Distances

Distance (Feet)	Angle (Degrees)
5000	0.17
4000	0.22
3000	0.29
2000	0.43
1000	0.86
500	1.72
250	3.43
125	6.84

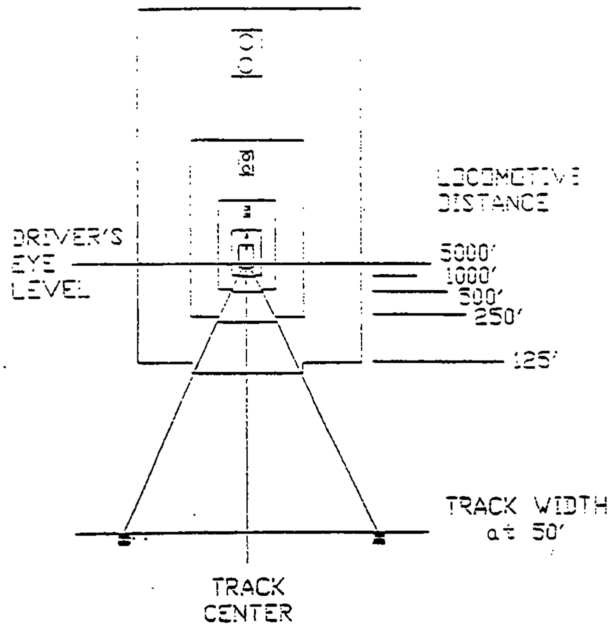


Figure I-3 Visual Angles

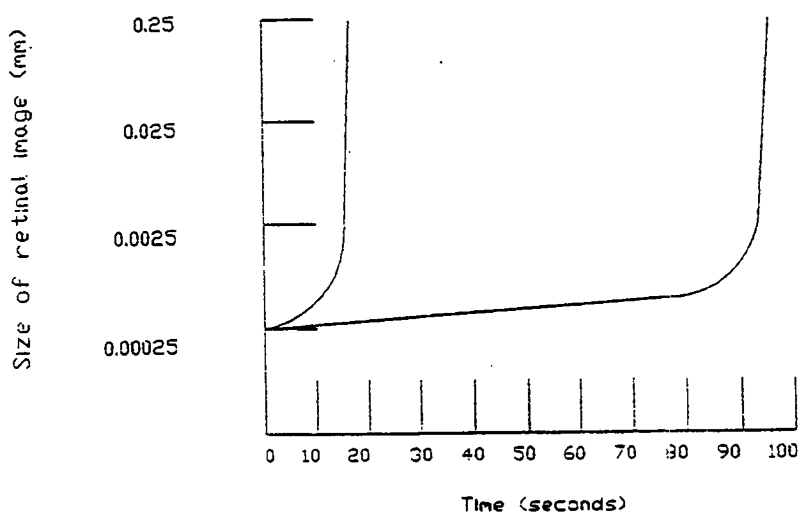


Figure I-4 Retinal Image Size

In considering the appropriate rate of expansion for the target, we considered some likely traffic scenarios. Assuming the Diverging Lights display changes phase at approximately one second intervals, what is a realistic rate of expansion over a one second period? We looked at this question for three starting distances (1000, 250, and 50 feet) and two travel speeds (25 or 50 mph). The growth of the retinal image under these various conditions differs dramatically. These growth rates are presented In Table I-3. The differences in "realistic" growth rates suggest that the values actually selected may need to be tied to specific assumptions about the situations (speed and distance) under which they are intended to influence the driver.

Table I-3

GROWTH OF RETINAL IMAGE OVER ONE SECOND PERIOD

	Speed	
Distance	25 mph	50 mph
1000'	5.9%	11.8%
250'	17.4%	40.6%
50'	263%	

In selecting parameters for an image expansion rate for the lamp pattern, it also must be kept in mind that there is an actual expansion, due to the two vehicles actually closing, which will perceptually interact with the apparent expansion that is induced by the light display. It is not known if these two sets of perceptual changes are simply additive in the real world situation.

Keep in mind that in the real perceptual world, as the angular distance between two lamps increases, the angle subtended by each lamp also increases, and by the same amount. In other words, the overall dimensions of an object, and of all the component parts of that object, grow at the same rate. Thus for maximal realism, each lamp diameter should grow in proportion to the increased divergence between lamps. Violating this perceptual rule will weaken the illusion, but the actual importance of this will depend quite a bit on viewing conditions. At a distance, at night, the lamps will essentially be point sources, and so their dimensions are not critical. Under better viewing conditions, differential growth rates for different display parameters may be disruptive of the illusion of a looming object.

In addition to the rate of growth of the image, there are other important parameters to the design of the light display. For example, the "duty cycle" is composed of an "on" period during which a pair of lamps is lit, and an "off" period before the next pair of lamps is lit. In terms of inducing a perception of "looming," a brief duty cycle, with no "off" period, would probably be optimal; this approaches animation in its effect. On the other hand, some off period, giving the display a flashing aspect, certainly would improve its attention-getting qualities.

The pattern of the display of lights is another design matter. A four-lamp array, with two dimensions of expansion, may be more effective than a two-lamp array, but would require a much larger display face. Neither type of array, however, would provide directional information, which could be quite important. One suggestion is to use a chevron-shaped array of lamps. The array would "expand" simply by illuminating additional lamps at the ends of the chevron arms. A directional indicator, such as a chevron, may benefit drivers by indicating the need for a lane change, as well as by showing the proper path around the maintenance vehicle.

In designing the optimal Diverging Lights type of display, it will of course be necessary to take into account available hardware and other practical engineering limitations (including the fact that lamps in successive phases cannot "overlap"). Among the key perceptual questions faced during design, are: what parameters are optimal for "loom"?; what violations of "reality" matter?; what are the tradeoffs of perceived closing vs. device conspicuity? To answer questions such as these, it is really necessary to do some perceptual studies. Short of this, however, it will be important for the designer to be able to compare the wide variety of alternatives. We have developed a simple program for computer simulation of a diverging light array, which allows ready comparison. The illuminated lamps are simulated by filled dots of any desired size. The program assumes a cycle of three phases (three different sets of lamps). This simulation could be used for perceptual experiments or as a design tool. For example, comparisons can be made of displays with or without expanding lamp diameters; it is quite apparent that the expansion in lamp size enhances the illusion of approach.

The computer program is allows the user to specify the following display parameters:

Display pattern (2-dot, 4-dot, chevron)

Spacing (offset of dot from center of display)

On time (lamp is lit)

Dark period (between successive lamps)

Blank period between cycles

The various sets of parameters can be saved as files, and run successively in batch mode. The program can be quite useful in illustrating the importance of these parameters in inducing a feeling of "approach" and in altering the extent to which the display commands attention.

Summary

Some type of dynamic light display with an "expanding" aspect appears to be a promising concept for inducing a perception of "looming," which is a major cue to closing rate. The simple two-dot diverging light configuration shown in the submission may not be the most effective design for implementing this concept, and a number of important design parameters warrant careful consideration. However, the basic concept appears promising, and there seems to be little risk associated with the concept even if it is not particularly effective.

Description of Adopted Design

The design for the prototype of the diverging lights was based on the probable need to vary both the lens size and spacing and the timing of the flashing lights. The adopted design is shown in Figure I-5.

The frame for the lights are designed with a metal rack that can be adjusted to any size light and any spacing between the lights. Len sizes shown in Figure I-5 are 2 1/2", 5" and 12". Initial center to center spacing of the 3 size lamps are 7.5" apart for the 2 1/2" lenses, 30" apart for the 5" lenses and 72" apart for the 12" lenses.

An additional 12 volt battery will be added to the vehicles' electrical system to power the diverging lights.

Initial lamp on time will be set at 2 seconds with 0.5 seconds between phases. The controller for the phase timing will allow for full adjustment of each lamp and time between phases.

Top and bottom brackets were also designed to mount the lights on the rear of a dump truck.

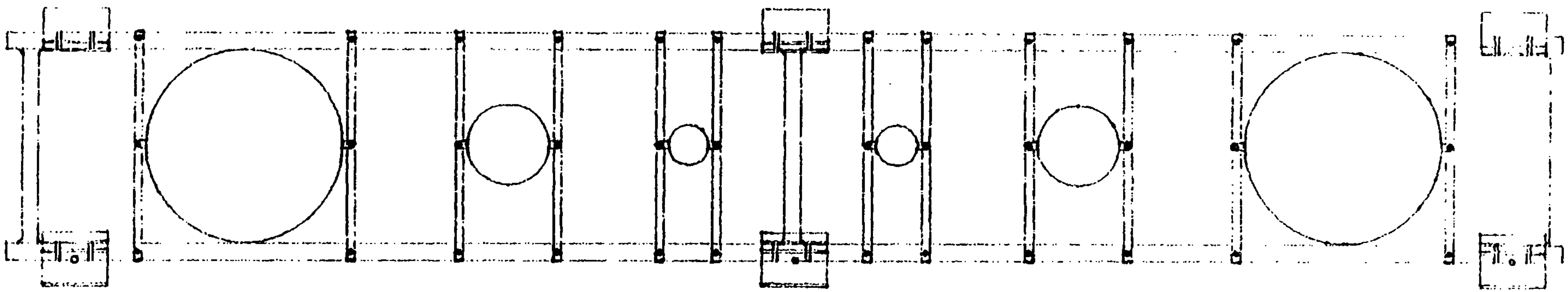


Figure I-5 - Diverging Lights

Attentive Signing Device

Human Factors Evaluation

Driver Task As Related To The Device

The device is a warning light which is to be mounted on an advance warning sign. It is intended to call attention to the sign and emphasize the hazard warning aspect. In order to function effectively, the device must catch the attention of the unalerted driver. Once noticed, the imminent hazard warning aspect must be comprehended and associated with the message of the warning sign. Furthermore, the driver must accept the warning light as credible (i.e. reliably indicating serious risk) if it is to influence his driving behavior.

Benefits

Through giving greater salience to the warning sign, and thus generating greater driver caution, the device is expected to reduce the risk to work crews, flaggers, and motorists. The submitter of this concept described his experience using flares in conjunction with signs at work sites where the signs were not being effective. In particular, a site with a steep grade and curve was experiencing trucks failing to brake effectively. The use of the flares reduced the frequency of such incidents. The warning light proposed would have an advantage over a flare in that flares have to be checked regularly and replaced.

Problems/Concerns With The Concept

The first general concern with this submission is whether it is really proposing any innovative concept. Although the light and its power source are not well described, it is intended to be a small bright light, attached to the sign, consistent in color with MUTCD requirements. It may be that the submission is simply describing an application for the MUTCD Type B High Intensity Flashing Warning Light (Section 6E-5). As described in the MUTCD, these lights "are normally mounted on the advanced warning signs or on independent supports. Extremely hazardous site conditions within the construction area may require that the lights are effective in daylight as well as dark, they are designed to operate 24 hours a day." The proposed "new" device seems highly redundant with this existing TCD, for which there are already specifications in terms of mounting, color, visibility, etc.

One manner in which the attentive signing device might be intended to differ from a Type B light is that the lamp may be meant to illuminate the face of the sign, rather than be directly observed by the driver. This application is not explicit in the proposal, but could be intended. There are some potential problems with this concept, however. In bright daytime conditions, the illumination of the sign face is unlikely to be very noticeable. A flashing aspect, and use of a colored lamp, might help, but certainly the conspicuity will be nothing like that of a directly viewed lamp. Power requirements for a sufficiently bright lamp might produce maintenance problems of frequent battery replacement. Furthermore, if the sign face is made of retroreflective material, most of the light will be reflected back in the general direction of the lamp, and not toward approaching drivers. Of course if the sign is not retroreflective, its nighttime visibility under headlights will be reduced, so that the lamp itself will have to be the primary illumination source. Since the lamp is mounted so close to the sign face, there are likely to be problems in evenly illuminating the sign face. Since the car headlights will also illuminate the sign, this will tend to "wash out" the illuminating (and color) effects of the lamp, so that the dramatic aspect of the "warning" may be lost. A final concern, particularly at night, is with potential color shifts if colored light sources are used. The apparent color of a surface can be dramatically changed under certain kinds of illumination; for example, high-pressure sodium lamps can change the perceived color of the surfaces they illuminate. This apparent color shift could be especially pronounced if only the sign face is illuminated by the colored lamp, as opposed to an entire roadway area. Therefore under night viewing especially, the perceived color of the sign might not match MUTCD color designations. The seriousness of this problem probably depends on the spectral characteristics of the light source as well as the normal color of the sign. For example, work at the National Bureau of Standards found that both low-pressure and high-pressure sodium lamps caused a very clear shift in the appearance of an orange sign, so that it appeared yellow. However, yellow still has safety implications for roadway signs, so this may not be a critical problem. Perception of red signs, however, is very badly distorted by low-pressure sodium lamps, appearing to most people as either brown or yellow. The major point here is that if some form of colored illumination is provided for the sign, the actual appearance of the sign, especially under night viewing, must be carefully determined and considered.

Another concern is that the warning device will lose effectiveness to the extent it is widely deployed. Its influence on driver behavior will depend upon restricting its use to those truly hazardous situations where extreme caution is essential. If more widely used, a large part of the driver response will be transient, as motorists come to view the light as a familiar and uninformative part of the work zone TCD array. Therefore the applicability of this device is (or should be) very restricted.

The last general concern has to do with the perceived credibility of the warning light for the motorist. The submitter initially began with the use of a flare, but felt that the warning light would have advantages, in particular not having to be frequently checked and replaced. However, a flare has very high credibility because it is temporary and is only used under unusual conditions. If a flare is ignited, the driver's assumption must be that someone recently set it off because of a currently existing risk situation. If a warning light can remain on for extended periods, this inherent validity to the motorist is lost. Furthermore, lights are common in many construction and maintenance situations. Therefore the anecdotal benefits described by the submitter, as he experienced deploying flares, may not be fully retained with the "improvement" of using lights instead.

Unknowns

There are no "unknowns" related to the basic concept.

Design Considerations

The design and use of the device should be such as to provide adequacy in three general respects: insure the visibility of the light (day and night); convey the idea of "hazard"; and protect the perceived validity of the warning.

The visibility aspect will relate to lamp intensity, area, and mounting location. All of these concerns are already addressed in the MUTCD for Type B Warning Lights (Section 6E-5). As with Type B lights, the device should flash to provide better conspicuity. Some dimming capability may be required to insure that adequate daytime light intensities do not provide a glare source at night. Again, we must raise the question of whether there is anything about the proposed device which makes it distinct from a Type B Warning Light in general.

The "hazard" message can be enhanced through several means. Presuming the device is a light (rather than a flare), an amber signal would be the standard color to convey caution. This is the color prescribed in the MUTCD for warning lights and hazard identification beacons. The immediate proximity to the advance warning will also serve to associate the light with the hazard message, so that attaching it to the sign or sign stand is probably a good idea. Also the flashing aspect of the light is intended to convey a sense of hazard.

If the device is to reliably convey a sense of hazard over repeated applications, the perceived validity of the warning must be maintained. In order to preserve this meaning, the following should be considered:

Warrants for use of the device should be strict and limited, so that its occurrence is not commonplace;

Every use of the device should be reliably followed by an obvious hazard. The device should not be active when the hazard does not exist. If the hazard is not obvious, it would be useful to make it more apparent, through signs, markings, etc. at the point of the hazard;

The device should be used in reasonable proximity to the hazard. If the threat is not imminent, the warning may be perceived as a false alarm, or at least the need for immediate and maintained vigilance will not be reinforced.

Another factor that should be considered in the design of the device is that it should be readily discriminable from other work zone lighting and TCD's. The effectiveness of the warning light as an indicator of special hazard depends upon the motorist seeing the device as different and meaningful. Work zones may contain a variety of other lights, such as steady burn lights on barricades. The advance warning light should stand out as distinct from the rest of the delineation array. The intensity and flashing character of the light will help in this respect. However, both through placement and perhaps other features (e.g. size, shape) the warning light could be kept distinct as an advance warning of severe hazard, and not "lost" in the general array of delineation elements. A final design consideration is whether the light is really the optimal means of providing this warning. The submitter of the idea described the success he has had using flares. Flares may have a number of advantages. They are of a unique color and intensity, their "burning" appearance is unique, they are associated with emergency applications, and their temporary nature supports the perceived validity of the warning. The submitter raised the question of whether an "extra-long" flare could be used. It might be that some other alternatives are possible to provide a flare-like appearance from some more practical source. For example, perhaps some controlled gas cartridge could provide a steady, long lasting flame, or perhaps the color and flicker of a flare could be simulated by various lights. It might be worthwhile to give some design consideration to retaining the inherent advantages of the flare, while avoiding the problems of short-term and unreliable activation.

Summary

This proposal is not necessarily for a new device or application, and can be viewed as an application of a Type B High Intensity Warning Light. Its effectiveness for this application can be enhanced if use is carefully limited and application criteria are strict. However, the proposed light may not be as effective as a flare, as the submitter described his experience with the flare.

If the intent of the lamp is to serve as a source of illumination for the sign face, rather than as a signal to be directly observed itself, there are serious concerns about its effectiveness for day or night applications.
Based on the human factors evaluation this concept was abandoned.

Police Light Assembly

Human Factors Evaluation

Driver Task As Related to The Device

The driver's task, as related to the proposed device, is somewhat ambiguous. Upon detecting the lights, he must recognize them as indicating some police activity. However, the most appropriate response upon recognizing the nature of the display is not clear, although some slowing can be expected. The submitter sees the police light display as provoking an "immediate response" to "automatically slow down." After this initial response, the driver's task would appear to become more ambiguous. Should he be attending to the "police situation" or the work zone situation? He has no way of knowing that the police light assembly is in fact related to the work zone activity.

Benefits

The presumed benefit of this device is that it will result in more reliable, immediate, and greater speed reductions, and alert drivers to a potential hazard area. Also it will increase the detection distance and conspicuity of the work zone.

Problems/Concerns With The Concept

The underlying logic of this approach appears to be to "trick" the driver into reacting to work zone TCD's as though they instead indicated the presence of a police vehicle. Therefore any benefits can be expected to be transient. As drivers repeatedly encounter these devices at different work zones, or repeatedly in the same location, the driver will no longer be fooled into thinking there is actually police activity.

At the same time, this application of the police light assembly will result in confusion over the meaning of real police situations. The light assembly will lose its credibility as an emergency display. It seems highly unlikely the law enforcement agencies would find this proposed application acceptable.

In addition, there are potentially serious problems in the driver response to this device. Because of its possible "emergency" connotation, some drivers may slow dramatically or make other erratic maneuvers. The appropriate response to police lights is not well defined, so that driver response in a work zone cannot be expected to be orderly. There may be more potential for traffic conflicts, since there may be more speed variability and less predictability in the traffic stream, as some drivers slow, others attempt to move over a lane, some simply continue as before, and others may attempt to "rubberneck." The police lights are designed for emergency alerting, not orderly traffic control. To the extent the lights are used in conjunction with normal work zone signing, there may be more confusion. The driver may not know whether the light assembly is part of the work zone guidance system or an independent police activity. The police light assembly may distract driver attention from the task of navigating the work zone, since the driver may be searching for the emergency situation, or be curious about the novel display of post-mounted unmanned police lights.

Unknowns

There are no important "unknowns" that bear on human factors aspects.

Design Considerations

There is little to specify in the way of human factors design of the light display, since the logic is to duplicate already existing police light assemblies.

One set of human factors considerations could revolve around the best placement of this device, and how it would best be integrated with other work zone TCD's. However, it does not appear worthwhile to pursue these details, given the basic problems with the concept.

Summary

This device may simply be considered inappropriate for work zone applications. Positive effects are likely to be transient, and negative effects may be serious. Based on the human factors evaluation this concept was abandoned.

Appendix J

Sign Fabrication and Testing

Introduction

Six devices are included in the signing study area. Three of the devices are used in flagging operations.

The Flashing STOP/SLOW Paddle and the Flow Through STOP and SLOW Paddle are both alternatives or improvements to the standard flagger paddle.

The Flagger Gate also replaces the flagger paddle and allows a flagger to remain on the shoulder of the roadway at all times.

The Alternate Merge Sign is an additional sign message to be used in advance of lane closures.

The Portable Sign and Stand is an alternate material for a sign and an alternate way of mounting the sign.

The Truck Mounted Message Box is mounted on the rear of a maintenance vehicle and contains a set message about the maintenance operation being performed.

The tasks involved in the development of signing devices are shown in Table J-1. Tasks 1 and 2 will be completed in Project H-108 and Tasks 3-7 are scheduled for completion in Project H-109.

Human Factors studies of the various sign messages to determine the potential of each proposed sign and final design of each sign and mounting hardware are detailed in this appendix. The human factors studies investigated the driver tasks related to each device, the expected benefits of the device, problems or concerns, unknowns, design considerations, and the overall prospects for behavioral effectiveness.

The information contained in the human factors studies led to abandoning of some concepts, and modifications to other original proposals. Based on the human factors studies the Flow-through STOP/SLOW Paddle and the Alternate Merge signs were abandoned.

The human factors studies of each device are detailed below. Design details are also discussed for all accepted devices.

In Project H-109 the signs and mounting hardware will be fabricated and tested in closed track and open highway environments. Specific mounting hardware will also be crash tested (in an abbreviated manner). Implementation packages will be prepared for each successful sign.

Table J-1

Tasks for Sign Fabrication and Testing

Task 1 - Human Factors Studies	Review relevant research and poll drivers to determine potential of proposal sign.
Task 2 - Finalize Device Designs	Based on human factors studies, generate final designs for each sign including supports and mounting.
Task 3 - Fabricate Device	Construct signs to permit testing in typical work zone array.
Task 4 - Test signs in closed track environment	Conduct day and night test of signs in typical closed track work zone. Eliminate ineffective designs.
Task 5 - Crash test mounting Hardware	Test specific mounting hardware.
Task 6 - Test Signs in Open Highway Environment	Obtain approval for experimentation and test signs in actual maintenance work zones.
Task 7 - Implementation Package	Prepare guide to use of new signs in maintenance work zones.

Flashing STOP/SLOW Paddle

Human Factors Evaluation

Driver Task As Related To The Device

The function of the device is the same as any other stop/slow paddle: it alerts the driver to the hazard and the need to take some action, and informs him of the proper action. The driver must detect the sign, recognize the hazard ahead, and comprehend the action to take, all in a sufficient time to permit a safe, controlled maneuver. The "innovative" aspect of this device, from the driver's perspective, is directed at conspicuity (detecting the sign at a sufficient distance). The flagger's task is modified by the device, giving him active control over two forms of additional communication: (a) alerting approaching traffic, by actuating the halogen lamps; and (b) alerting work crews of an emergency situation through sounding of a horn. Driver detection of the device is aided by both the greater conspicuity of the TCD and also the more active role of the flagger.

Benefits

The proposed device actually consists of three essentially independent features, each with its own benefits.

One feature is the flashing high-intensity halogen lamps which the flagger can activate to alert oncoming traffic. The benefit of this is to improve conspicuity, resulting in earlier detection of and response to the paddle.

The second feature is the "folding mask." Rather than alternating between the "STOP" and "SLOW" messages by rotating the paddle, the messages are alternated by flipping a hinged mask which covers the paddle face. When folded back, the "STOP" face is seen; when opened, the mask obscures the "STOP", and "SLOW" (or some other desired message) is seen. The rear of the paddle always shows the "SLOW" message. The stated benefit of this design is that there will be less confusion to drivers approaching from behind the flagger, since the "STOP" message will not be seen.

The third feature is a warning horn. This horn can be intentionally activated by the flagger, or automatically activated if the paddle is dropped (by removal of a pin attached to the flagger's wrist strap). This gives the flagger a means of alerting workers to an out-of- control vehicle or other dangerous condition. It also provides another means of getting a motorist's attention, in a potential emergency.

Problems/Concerns With The Concept

While there are several human factors design issues concerning this concept (discussed below), there are also two basic perceptual concerns which must be considered. One of these basic issues concerns the flashing light, and the other concerns the acoustic alarm.

One concern is with the potential masking effects the bright flashing lamps may have on the legibility of the sign face itself. There are a variety of perceptual effects, under the general heading of "masking", that occur as a result of the spatial and/or temporal relationships between visual stimuli. Predicting the magnitude of these effects for the proposed device would be difficult, since the details of the spatial relationships, flash rates, bulb brightness, ambient luminance, and so forth all might influence the outcome. However, it is at least reasonable to expect that some degradation of sign legibility would occur as a result of the bright flashing lights proximal to the message. The magnitude of any such effects, under likely operational conditions, will have to be determined. As a very crude but simple simulation, we placed an 18" stop sign paddle face next to a normal slide projector, and viewed the sign while the projector lamp was flashed on and off (projectors use halogen lamps). There was a very obvious degradation of the "STOP" message, as well as a washing out of the sign color. We are not implying effects will be as strong under field conditions, but the phenomenon may be inherent in the device concept and must be evaluated.

Another possible problem with this concept is the level of sound required to make the acoustic warnings effective. The alarm is meant to alert either the construction crew or the unalerted driver. In either case, sound levels at the flagger position would have to be intense. In either case the intended listener (work crew or driver) is potentially at a substantial distance (e.g. 250 feet; Section 6 of the MUTCD describes the "desirable" flagger position as 200-300 feet in advance of the work zone) and in a noisy operating environment. Considering the problem of alerting the driver, research (Aurelius and Korobow, 1971) has suggested that a signal intensity of about 87 dB is required outside the vehicle in order for a horn to be reliably heard. This estimate, however, may be quite specific to the study's test conditions, which did not represent "worst case" conditions of loud radios, noisier vehicles (e.g. trucks), or older drivers with typical age-related hearing loss (presbycusis). Furthermore, since sound intensity reduces over distance by the inverse square law, sound levels decrease by 6 dB per doubling of distance. Thus the sound at 250 feet away is about 36 dB quieter than at a point 2 feet from the source. If one wishes to provide a signal adequate to alert a work crew or driver 250 feet away, it must be remembered that the flagger (assuming about a 2 foot distance) will hear a sound 36 dB louder than at the target listener position. Thus if the objective were to present an 87 dB signal at 250 feet, the sound at the flagger position might be 123 dB, exceeding the threshold of pain. While acoustic warnings for work crews, and possibly for drivers, might be desirable, it may not be appropriate to originate these signals at the flagger position a considerable distance away.

Unknowns

It is not known whether the bright flashing lamps might interfere with balance and coordination of flaggers. Equilibrium is known to be sensitive to visual input in various ways, and real or illusory movement in the periphery can be especially disruptive. If the surrounding area is alternatively illuminated, then not illuminated, by the high-intensity lamps, the effect may be strobe-like, at least under some ambient illumination conditions. Since the flagger is standing in such close proximity to traffic, anything which might increase the probability of a fall, trip, or large body sway could have serious consequences.

Another unknown is how much hesitancy there might be on the part of the flagger to sound the acoustic horn. There are various reasons why the flagger might be reluctant to activate this alarm. As noted, the acoustic signal would have to be quite loud in order to be reliably heard by workers and drivers. The flagger conceivably might wish to be very sure there is no "false alarm" before triggering this sound. First, it would disrupt work activities, cause panic, and be annoying to the work crew. Second, the driver response to this intense sound is unpredictable, and could even be erratic. In any case, the driver might be angered or afraid. Finally, the loud sound, immediately next to his head, will be aversive to the flagger. The situation essentially defines what is known in psychology as a "punishment" paradigm, and intense sound is well demonstrated to be an effective punisher. This means that any behavior that results in such a sound is less likely to occur, or will occur with a long delay. Thus for all of these reasons, the flagger may hesitate to activate the acoustic warning. This hesitation in turn could reduce the potential effectiveness of the alarm, since the period for response would be reduced.

It is also unclear what visual cues a flagger will use to determine whether an approaching vehicle is out of control, and at what point this decision can be reliably made. This is important because it will determine whether the flagger has adequate time to alert the driver, adequate time to alert the work crew, and adequate opportunity to evaluate the situation so as to avoid a high rate of "false alarms."

Design Considerations

Two design considerations are important for the flagger. First, there should be adequate masking of the lights so that the flagger, in normal position, is screened from direct view of them. Second, since the flagger will normally not be able to see the paddle face, there should be some unambiguous cue indicating to him what message is being shown (folding mask position). We suggest a tab at the base of the mask, readable by the flagger, which indicates the message being shown. This redundant cuing should reduce errors in showing the inappropriate message.

Depending on the intensity of the halogen lamps, they may be a glare source for passing vehicles. If the flagger initiates the lamps to alert an approaching vehicle, a leading vehicle, near the flagger, might see the lamps at close range at about eye level. Brightness factors will have to represent a compromise between advance warning functions and potential glare problems. The advance warning function will also have to be weighed against the other possible problems noted that relate to the flashing lamps (masking of sign message, impaired equilibrium, visual disturbance or annoyance to flagger).

The acoustic aspects of the alarm must be carefully defined. Intensity levels and other acoustic parameters should be related to expected noise conditions at the site of those to be alerted (the work crew). Given these requirements and the expected maximum distances from the flagger to the crew, the required sound levels at the paddle itself can be determined. These may not be realistic or safe. In such a case, some form of remote signalling may be considered (e.g. radio signal that activates an alarm located near the work crew).

Summary

Since the design concept really is composed of three independent elements, the potential of each can be considered separately.

If it is not awkward in actual use, the folding mask should cause no problems.

The flashing lamps would appear to hold promise as conspicuity improvements, and as a means of allowing the flagger to take a more active alerting role if a driver is suspected of being inattentive. The overall benefit, however, depends on overcoming a number of concerns explained above.

The warning horn may be useful under some limited conditions. The sequence of events that must take place is: (a) flagger must detect cues that suggest a vehicle is errant; (b) flagger must go through verification/decision process to determine that alarm should be sounded; (c) work crew must detect alarm; (d) work crew must search for cues to the emergency situation to determine what the hazard is; (e) crew must evaluate the situation and determine the appropriate action; (f) the evasive action must be completed. Each step in this sequence takes time. The effectiveness of the warning horn therefore will depend on site features, distances, and activities. It probably cannot be counted on to serve as a generally effective means of warning.

Description of Adopted Design

An illustration of the Flashing STOP/SLOW Paddle is shown in Figure J-1. The proposer of this concept has a prototype constructed with halogen lames. Since the proposer is Canadian the paddle is diamond-shaped. The proposer has agreed to add the folding mask feature to the prototype. The alarm feature will be modified top become a panic button feature that will set off a remote alarm near the work area. The panic button will also be actuated if the paddle is dropped by the flagger.

The proposers specification shut for the Flashing STOP/SLOW Paddle is shown in Figure J-2. No extreme changes are anticipated in these specification based on the modifications discussed above.

Flow Through Stop and Slow Paddle

Human Factors Evaluation

Driver Task As Related To The Device

The function of the stop/slow paddle is to alert the driver to the hazard and the need to take some action, and to inform him of the proper action. For the paddle to function effectively, the driver must detect the sign, recognize the hazard ahead, and comprehend the action to take. This must be accomplished with sufficient time and distance to permit safe execution of driving maneuvers. The "innovative" aspect of this device is not directed toward the driver, but toward

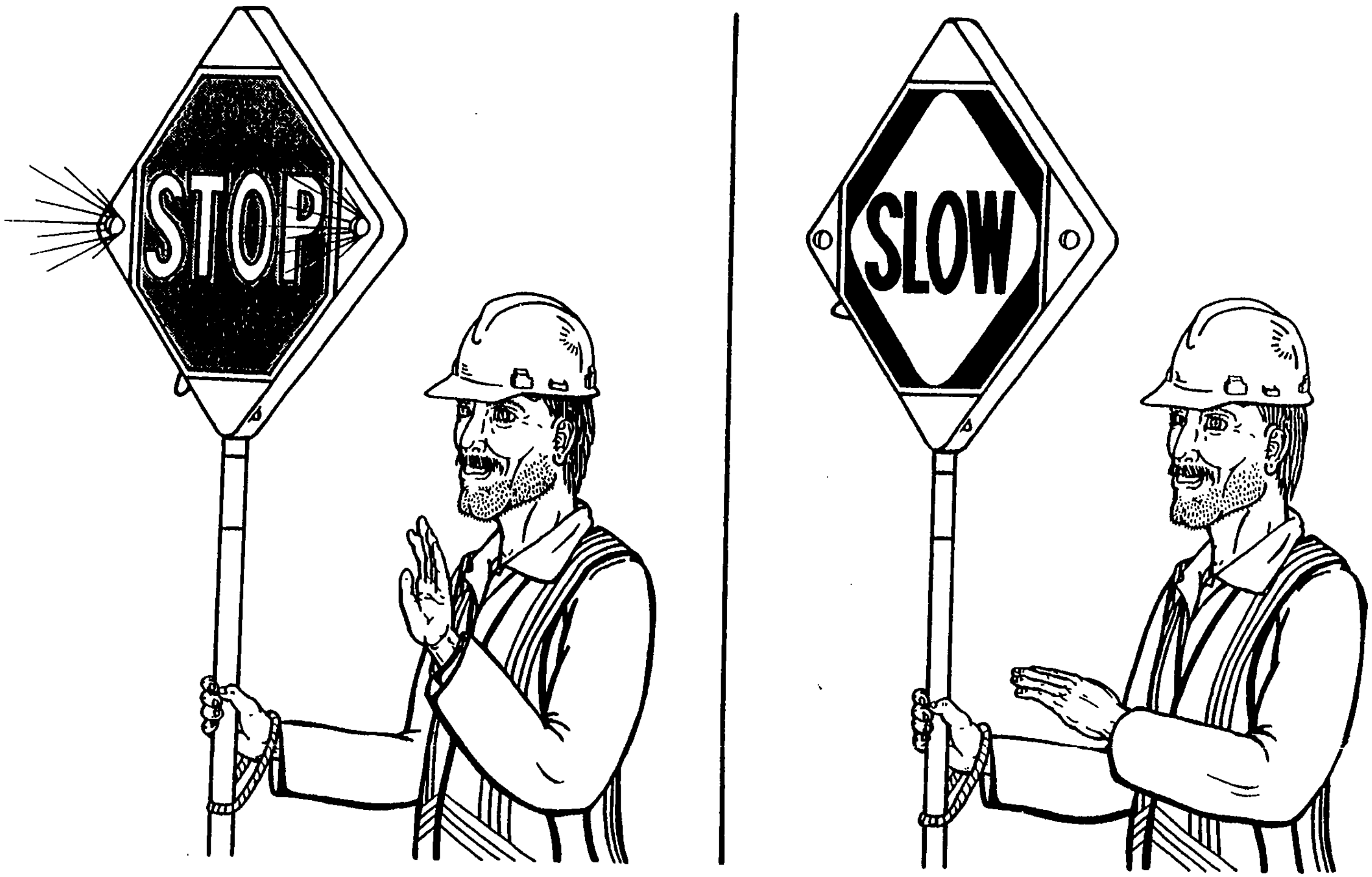
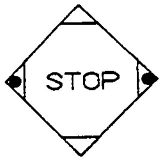
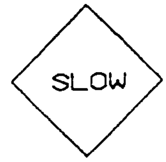


Figure J-1 - Flashing STOP/SLOW Paddle





The Detronics Flashing Stop/Slow Paddle uses two high intensity quartz halogen lamps,flashing alternately to bring a motorists attention to the flagman.With a single press of a button the lamps flash 10 times,then the system automatically resets itself.The unit is powered by rechargeable batteries located in the bottom of the staff in order to keep the center of gravity low. High intensity retroreflective sheeting is used on the stop side with fluorescent retroreflective sheeting on the slow side.For durabbility,light weight and high strength the paddle is constructed of anodized aluminum with stainless steel fasteners.

Weight		7.2Lbs
Overall Height		74 inches
Sign Size		18 X 18 inches
Battery Life *	Standard Batteries	350 cycles
	Hi-Capacity Batteries	1400 cycles
Lamp Life **		2000 hours

* Battery life indicates the number of cycles of operation before requiring recharge.One cycle = 2 lamps flashing,alternately,10 times each for a total of 20 flashes.In terms of hours,if the sign is cycled every 2 minutes, standard batteries will last for approximately 11.5 hours before requiring charging.

** Lamp and battery life are engineering estimates based on laboratory conditions and may vary due to shock,vibration,temperature and other variables.

The TES-336 Flashing Stop/Slow Paddle is made by Detronics Limited,designers and manufacturers of special electronic equipment.The electronic control is covered by a 3 year limited warranty for parts and labour. If service should be required,Detronics offers 48 hour turn-over.Contact your dealer or our Sales and Engineering staff,we are just a phone call away.

Detronics Limited whose policy is one of continous improvement,reserves the right to discontinue or change specifications,models,equipment or prices at any time without incurring obligation.

Patents pending in the United States and Canada

Detronics Limited
Stouffville,Ontario
Canada L4A 7X5
416-640-1216

Figure J-2 - Flashing STOP/SLOW Specifications the flagman. The flagger task is made more difficult in wind gusts, and the perforations in the sign are designed to reduce wind resistance. In accomplishing this end for the flagger, it is important to insure that device aspects related to driver performance are not degraded.

Benefits

The reduced wind resistance will require less effort on the part of the flagger, and less attention will have to be directed toward handling the paddle. Therefore it is argued that there will be resultant operational or safety benefits because more attention can be concentrated on traffic operations and crew safety. Also it is less likely that wind gusts would carry the sign into the path of vehicles. Benefits in stability for mounted signs also are expected.

The magnitude of the potential safety and operational benefits is not clear, since the frequency of wind-related work zone incidents is unknown.

Problems/Concerns With The Concept

The primary concern is that the holes in the sign field will disrupt driver perception of the sign. Although the suggested hole pattern avoids the immediate surround of the legend, this does not mean that detection or legibility will not be degraded. If nothing else, the pattern as shown would remove about 14% of the orange sign field on the "Slow" side. There will no longer be a broad contiguous area of solid color. Furthermore, the setting behind the flagger can influence the properties of the perceived sign field.

While there is certain to be some measurable degradation in sign perception, it may not be of great significance. To get a sense of the visual impact of the hole pattern, two sign mock-ups were produced. Each mock-up was an 18" double-sided octagonal paddle head, with "STOP" on one face and "SLOW" on the other. These conformed to MUTCD section 6F-2 in size, legend, and color. One of the mock-ups contained the pattern of 1/2" diameter holes as illustrated in the device proposal. The other mock-up had no holes.

In an informal evaluation, three observers viewed the signs, side by side, against a variety of backgrounds and daytime light conditions. In general the legibility of the legend ("STOP" or "SLOW") was not strongly affected by the holes. However, the conspicuity of the sign itself was substantially degraded under certain viewing conditions. In general, the paddle with holes appeared slightly less bright. But when the background against which the sign was viewed was of a light color and bright appearance, the sign itself tended to "wash out", especially on the orange (SLOW) side. The shape information was lost, especially on the SLOW side, and the intensity of the color was reduced. Under some conditions (e.g. a white building, in sunlight, some distance behind the sign), the sign field actually appeared at a distance to be a 6.5" by 18" rectangle (the small central area free of holes). Thus the important elements of shape and color coding were lost, and effective sign size could be drastically reduced.

This substantial loss of conspicuity and shape/color coding did not occur under all viewing conditions, but it cannot be assumed that the flagger would be sensitive to, or have control of, the viewing background. Even traffic passing behind the sign can disrupt viewing. In observing the sign against a backdrop of moving traffic, we noted the sign appeared to fade whenever a light colored vehicle passed behind it.

Another concern with the concept, as presented in the original submission, concerns the color of the sign. The proposer seems to be suggesting the use of some new "bright and bold" color, "something not seen everyday and at the same time <u>not</u> hard to see." The MUTCD clearly specifies the colors of signs, including work zone signs. It is true that the conspicuity of orange, in particular, has been criticized, and other (reserved) colors might be better seen. But there is no reason why this paddle, in particular, should be a distinct color from other work zone signage. If the submitter's suggestion is meant to apply more broadly to other TCD's, this would represent a fundamental change in work zone signing policy, and is not specific to the device under evaluation. Therefore the comments regarding color will not be addressed here.

Unknowns

One unknown factor is the degree to which the flow-through design will actually reduce the work load and improve the controllability of the paddle for the flagger.

Another unknown is the kind of visual background against which paddles are typically viewed. It might be the case that acceptable backgrounds exist in the large majority of cases. However, we are skeptical that this is the case. In fact, a light colored Jersey barricade may be a good example of the kind of backgrounds that can cause trouble.

Design Considerations

Some visual degradation is inherent in the device concept. However, the degree of interference will be related to the pattern of holes. It might be that fewer, or smaller, holes would provide less perceptual disturbance; however, the impact on wind resistance must be determined. Perhaps some modification, such as using vents instead of holes, would prove more effective in reducing wind load without reducing visibility. Perhaps some form of aerodynamic shaping of the paddle would be beneficial. The goal of trying to reduce wind load may be achievable by some approach different from that illustrated in the submission, but any proposed treatment should be thoroughly evaluated for driver visibility.

Summary

For this device to have a positive influence, it must significantly reduce the difficulties faced by flagmen handling the paddle, and these difficulties must be related to a meaningful number of work zone incidents. We do not know if either of these is the case. Even if so, the overall benefits will be reduced, perhaps even more than offset, by the greater difficulties drivers may face in detecting the paddles. Our experience with the mock-ups indicated that the device as currently configured should not be pursued, because of the visibility problems under certain conditions. However, alternative designs that may accomplish the same effects in reducing wind load, may be worth considering.

Based on the human factors evaluation, this concept was abandoned.

Flagger Gate

Human Factors Evaluation

Driver Task As Related To The Device

The manually operated gate replaces the flag or paddle. The driver's task in response to the gate is the same required in response to a paddle or flag: the driver must detect the device, recognize the hazard ahead, and comprehend the action to take. This must be accomplished with sufficient time and distance to permit the safe execution of driving maneuvers.

The "flagger's" task is unchanged. He must control traffic and help protect the work crew. This requires him to have adequate visibility of oncoming traffic, and the ability to operate the traffic control device in an accurate and timely manner.

Benefits

This device replaces the flagger using a paddle or flag with a manually operated gate. Since the gate operator is positioned on the shoulder of the road, he is less at risk of collision than in typical flagger positions which, while on the shoulder or closed lane, are closer to the travelled way.

Problems/Concerns With The Concept

There are several human factors concerns related to the basic device concept which will have to be carefully considered in the design and application of the device.

First, this device achieves its primary safety benefit by further displacing the flagger from the travelled way. However, this could result in some visual limitations for the flagger. If there is curvature to the road, or overhanging trees or brush, approaching traffic will not be seen as far in advance. The greater the displacement of the flagger from the road, the greater the protection, but the more likely visibility problems may be.

The gate and gate stand serve as roadside objects which themselves may be hit in collisions. It seems reasonable to expect more minor accidents if such gates are installed. The flagger should not be hurt under these types of collisions, but it is not clear if this will be the case. What happens if a vehicle impacts the stand? Even if the vehicle only hits the gate, could the flagger be thrown from the stand? Even trivial collisions with the gate arm might result in traffic delays. The general question here is, even if the device is successful in preventing direct collisions with the flagger, what will be the frequency and safety/operational consequences of the (presumably) more numerous impacts with the device itself?

Another inherent concern is whether this device is as effective in producing driver caution during the "SLOW" condition as are alternative devices (e.g. paddles). There are several reasons for this concern. One is that with the gate arm raised, the primary cue is the "SLOW" sign, which is displaced well off to the shoulder. Second, the presence of a human figure is a very salient visual cue to the driver, which commands attention; by removing the flagger, this salience is lost. Finally, the actual presence of a flagger gives credibility to the signage; there is obviously work activity going on. In the absence of work personnel, drivers may delay their actions until there is other visual confirmation that work activity is actually going on and that it requires some slowing and caution. For these reasons, there is reason to believe that there may be less cautious driver behavior if the flagger with a "SLOW" paddle is replaced by the raised gate arm with a "SLOW" sign.

Unknowns

The level of motorist compliance with the proposed device when the gate is lowered is unknown. The parallels of this device with railroad grade crossing gates are apparent, and various forms of risky behavior or poor performance are well known in this area (Lerner, Ratte', and Walker, 1988). These include trying to "beat" a lowering gate and driving around a lowered gate. The visual removal of the flagger from the work zone situation may reduce the driver's inhibition to ignore the TCD. However, the problem in the railroad crossing situation grows largely from the driver's perceptions that the signals are not valid. The train may be out of sight or at a distance, and there is no other impediment to crossing. This may not be analogous to the work zone situation (provided the driver comprehends that this <u>is</u> a work zone). The proposed device may have greater perceived credibility than the railroad crossing gate. The driver may not expect that he can necessarily see the hazard, and so may be more willing to rely on the TCD. There is more reason to expect a traffic conflict if the gate is driven around. Therefore we conclude that the proposed device has the potential for poorer compliance (relative to the flagger with a "STOP" paddle), but actual compliance will have to be measured in the field.

Design Considerations

The most important human factors design considerations center around the conspicuity and driver recognition of the gate arm and stop sign in the "STOP" situation. It is imperative that the driver detect and respond to the lowered gate with enough time to execute a safe stop maneuver.

The single gate arm illustrated in the concept presentation will have limited target value; the stop sign will be more effective as it is centered in the lane, but will be less noticeable before it is fully in place (arm fully dropped). The parallel of this device with comparable gates at railroad crossings deserves comparison. Rail-highway crossings have advance warnings signs and pavement markings to alert drivers to the upcoming crossing. Standard gates at rail crossings also are accompanied by a pair of red flashing light signals, as well as three red lights on the gate arm (one steady, two flashing). The gate arm has diagonal markings of red and white. Even with all of these conspicuity benefits, it has been found that "skirts" which drop from the gate arm when it lowers significantly improve target value and driver behavior.

To whatever extent possible, the gate proposed for the work zone application should have similar features. Good advance signing will be important for establishing the driver expectancy that a stop may be required. In fact, some new advance warning sign, used in place of the advance flagger sign, may be required. The gate arm must have skirts to improve its visibility. A variety of skirt designs are possible, and mechanical considerations may be important in the final choice. One recommendation is that the skirt involve parallel rails, so that the visual appearance is essentially that of a Type III barricade. A prototype device of this sort was studied by Heathington, Fambro, and Richards (1988) for a railroad crossing application, and found to have a "superb safety benefit." Since the proposed device functions as a barricade, the design specifications for a Type III (or Type II) barricade are a reasonable starting point for design. However, conspicuity improvements through arm-mounted or shoulder mounted lights would be beneficial. Since the flagger cannot do much to capture the attention of a driver who has failed to notice the device, the stop sign also should be prominent. Since the flagger paddle requires only an 18" sign, we suggest using a minimum 24" sign (MUTCD minimum for low volume roads) or two 18" signs on the arm. Also the height of the stop sign, as mounted on the gate is not specified, and might be lower than if it were held as a paddle by a flagger; consistent with MUTCD regulations for signs in general, it is recommended that the stop sign be mounted at a height of at least 5 feet (when gate is fully lowered).

In addition to the conspicuity issue, another human factors design concern will be the drop rate of the gate arm. The drop should not be so fast that vehicle collisions occur; but if the drop is too slow, drivers may be encouraged to try to "beat" the gate. It is not clear from the proposal exactly how the gate will be operated by the flagger. It may be possible to have the rate of descent controlled, e.g. by a piston, but it is not certain whether this is more desirable that full manual control (flagger may be able to avoid some collisions with the arm).

A final, related human factors issue is the flagger control of the gate arm in general. The arm should be light enough to be readily controlled, even while the flagger is concentrating on approaching traffic. If the design of the gate is such that it is heavy or awkward, some mechanical advantage or powered treatment may be needed. The flagger should not be forced to direct his vision or attention toward the gate itself during the critical period when approaching vehicles should be attended to.

Summary

The physical removal of the flagger from the immediate area of the travelled way will undoubtedly reduce pedestrian collisions. There are related concerns about degraded driver perception and behavior. Good human factors design will be critical to the success of this approach, and careful field evaluation will be essential. However, there does appear to be the potential to develop this concept in such a way that the net safety benefits make it worthwhile.

Description of Adopted Design

The design of the flagger gate is shown in Figure J-3. Both the down "Stop" and up "Slow" views are shown. The gate employees orange and white stripes on the rail and a 24" STOP is mounted to be 5' off the ground in the "down" mode. The base of the gate is equipped with small hard rubber wheels to aid in moving the gate.

Several features that are not shown in Figure J-1 include the mechanism to fold the gate arm in three pieces for transport and storage. A 1/2 scale model of the flagger gate was constructed using lumber and steel shaft and gears to pivot the signs. Based on this model expect to employ a fiberglass arm to reduce the weight that must be raised and lower. This material should also break easily if the arm is hit. Counterweighing the arm and a piston assist for raising or lowering the arm are also incorporated in the design.

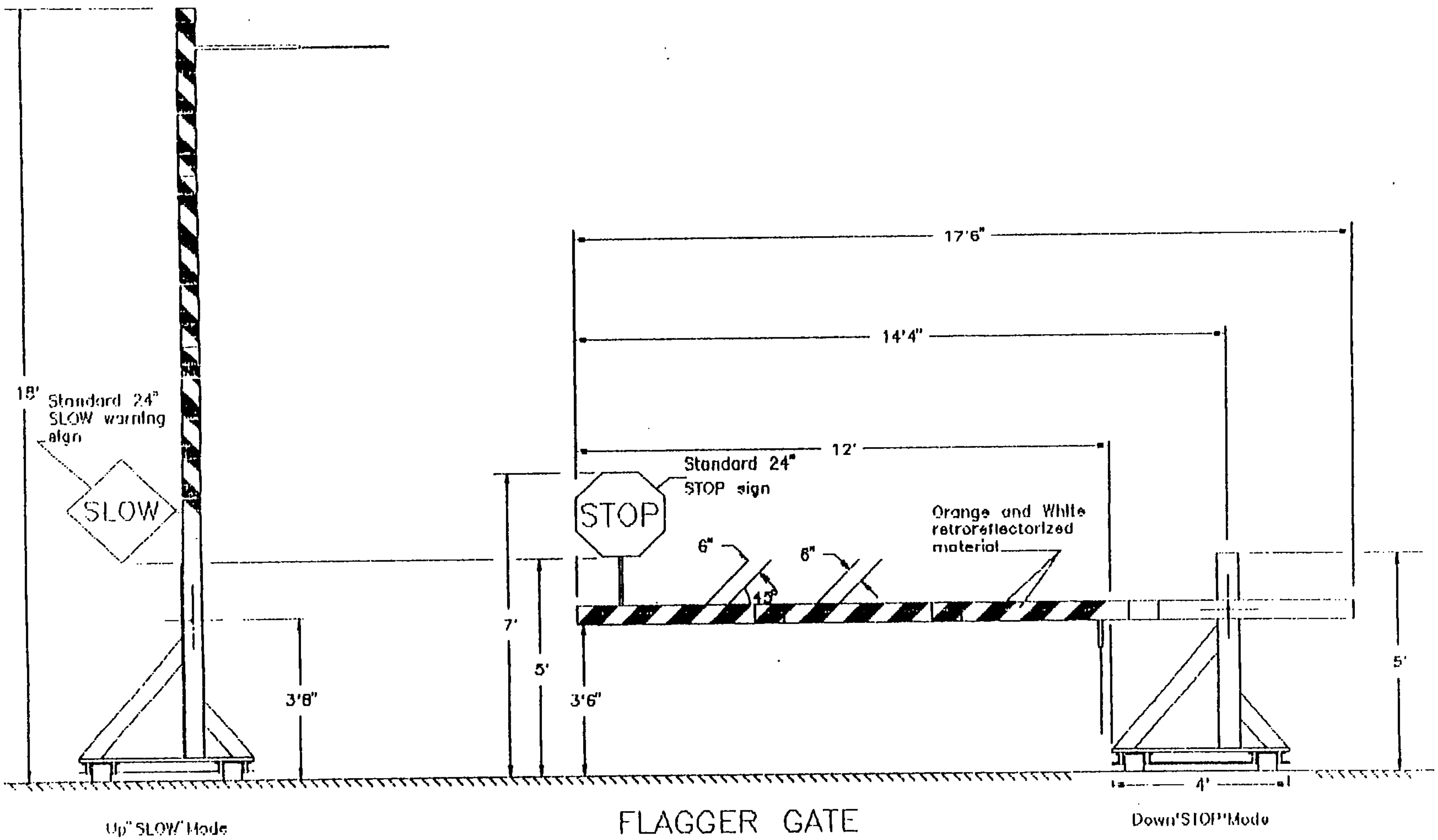


Figure J-3 - Flagger Gate

Skirts or lights on the arm will also be considered if field tests reveal the need for better conspicuity of the flagger gate.

Alternate Merge Sign

Human Factors Evaluation

Driver Task As Related To The Device

The purpose of the sign is to inform drivers in both the closed lane and the through lane of the appropriate action to take. It does not appear to be intended as an advance warning of work activity or lane closure, but rather to function almost as a regulatory sign, specifying a particular course of action.

In the simplest sense, this sign tells drivers in multiple lanes to "take turns" at a particular point. Each driver must recognize when it is his turn. However, the actual required actions are more complex than this.

Presuming that the driver correctly perceives and interprets the sign, he must recognize which action applies to him. If in the through lane, he is to let one adjacent vehicle in the gap between his vehicle and the one ahead. How he provides an acceptable gap is not specified, but presumably he will slow to permit an adequate opening if one does not exist. However, this slowing could simultaneously shorten the gap <u>behind</u> his car, intended for another vehicle.

Thus the complying driver in the through lane is trying to solve the problem of providing adequate gaps, front and back, while other drivers in the traffic stream are simultaneously trying to solve the same problem and influencing traffic dynamics.

The driver in the closed lane must recognize that he is to merge and that the drivers in the through lane are to open one-vehicle gaps. He must determine which gap is "his", that no other vehicle is intending to enter the same gap, and when it is safe to enter the gap. If a gap is sufficiently wide for more than one vehicle, "compliance" suggests that only one vehicle should enter.

Benefits

The intended benefit of the sign is to make the merge at a lane closing more orderly, thus reducing delay, conflicts, and accidents. With proper compliance, the delay or back up should be similar in both lanes, so that there is little incentive for rapid lane changes to get into a faster lane. It should be noted that these benefits, and the underlying incentive for individual motorists to act in accordance with sign requirements, would probably require a quite high degree of driver compliance within the traffic stream as a whole.

Since the intention of the concept is to reduce delay related to the interaction of vehicles in the traffic stream, the potential benefits are only for those sites, and at those times, when there is significant traffic.

Problems/Concerns With The Concept

There are a number of serious human factors concerns with this device concept. In order for a driver to comply, he must be able to understand the sign message, know the appropriate action to take, have the appropriate motivation to comply with the sign, and finally be able to execute the desired maneuver. There are potential problems with each of these aspects.

Comprehension problems are likely with this sign. First, the intended message, in both its pictorial and verbal (instructional plaque) forms, is not likely to be readily understood. The pictorial message is unclear, and there is no analogous sign for non-work zone applications which might serve as an aid to interpretation. The concept of "alternation" is not one that lends itself readily to a simple graphic image. An effective symbol sign should not have to rely on an attached instructional plaque in order to convey its meaning; but in this case, even the instructional plaque is not particularly effective. The intended message is not easily conveyed in a few words, and the chosen message is difficult to comprehend. Furthermore, the particular words used may present difficulties for people with poor reading skills. "Alternate" and "merge" require relatively high reading levels (7th grade and 12th grade, respectively, according to the IOX Basic Skills Word List).

We confirmed the inability of this sign to convey its intended message through a small and informal test. An appropriately colored (black on orange) illustration of an "alternate merge left" sign, including the educational plaque, was shown to ten COMSIS employees not involved in this project. As a group, this sample is far more educated and sophisticated with respect to traffic than the population as a whole. None the less, comprehension was exceedingly poor. Only three people understood the message, and two of these individuals, without prompting, added that they would choose to ignore the "alternate" part of the message. The remaining seven people suffered from a variety of misinterpretations. Most (though not all) understood to merge left, but the idea of alternation was not conveyed, and the use of the word "alternate" was very confusing to them. One even interpreted the sign to indicate that moving to the left was an alternative, not a requirement. Virtually everyone questioned stared at the sign for a significant time, with a very puzzled look, and volunteered that the sign was confusing or unclear. While no measure of "comprehension time" was taken, it was apparent that even for those few who eventually understood the sign, this was as a result of deliberation, rather than understanding at a glance. This small survey, while not intended as a formal sign comprehension experiment, was sufficient to confirm our opinions as experienced researchers in sign design, that the alternate merge sign, even with the educational plaque, will suffer from serious limitations in understandability.

Even if a driver comprehends the intended message, he must then recognize the action to take. In their comprehensive study of "Determination of Driver Needs in Work Zones", Hostetter et al. (1982) identified criteria for effective work zone signs. These included the "Driver Response Criterion": Does the device clearly communicate exactly what the driver must do?; and the "Reference Location Criterion": Does the device clearly specify where the driver must respond? The Alternate Merge sign is lacking in both of these respects. Much of this ambiguity stems from the fact that there is no single "merge" point, but rather an extended approach and transition area. In fact, the submitter of this design recommends a minimum of two alternate merge signs, one in the advance warning area but well in advance of the transition area, and the second at the beginning of the transition area. If the driver is in the closed lane, where is the point at which he should move? Is it inappropriate to change lanes in response to the advance warning signs? At the first "alternate merge" sign? At the transition (taper) area? If an adequate gap does not open immediately, at what point should he look for another driver to let him in? Once he has entered the through lane (e.g. near the initial "alternate merge sign" in advance of the transition area), does <u>he</u> now have the obligation to let vehicles in from the blocked lane in too? How does a vehicle in the obstructed lane know whether any particular vehicle in the through lane is one which has recently merged into the lane, or has already allowed another vehicle in? Thus even if a driver comprehends that this sign is telling motorists to "take turns" in channelling into the open lane, it is ambiguous as to when and how to do this.

The next concern is that even if a driver knows what he is being requested to do, will he be motivated to act in the appropriate manner? Driver interview studies show that a significant number of motorists (e.g. 20%) admit that they delay merging in an attempt to pass traffic. Even those drivers who prefer to change lanes as soon as possible (about 50% in one on-road survey, Gardner and Rockwell, 1983) may in effect not be complying with the action called for by the alternate merge sign. The individuals questioned in our small sample, described above, expressed considerable skepticism about compliance, and some volunteered that they would not change their own behavior in response to this sign. Compounding the compliance problem, there is very little enforcement activity at work zones, and this would be a difficult action to enforce (in fact, if it does not have regulatory sign status, it may not be enforceable). Widespread compliance would mean that a significant number of motorists at a given site would have to give up a perceived "advantage" (e.g., uninterrupted movement in the through lane, or temporarily fast and unimpeded movement in the closed lane) in return for greater benefits for the entire traffic stream. Motorists would also have to be willing to voluntarily allow large vehicles, such as trucks or buses, ahead of them or behind, even though many drivers find this uncomfortable. It seems unlikely that certain aggressive drivers would alter their behavior in reaction to the proposed sign. In the original proposal the proposer argued that there would be little incentive to change lanes abruptly, since both lanes will be moving similarly. However, there is a certain danger to this somewhat circular argument, since the presumed effect, which it is felt will foster compliance, is itself already based on the assumption that there is good compliance.

Finally, if a driver understands what is required and wishes to comply, will he be able to execute the required maneuvers in a safe and timely manner? If a motorist in the closed lane reaches the transition (taper) area without an adequate opportunity to merge and so must stop or slow drastically, the sign has failed to accomplish the intended operational benefits. Because of the ambiguities in where and how to merge, including possible uncertainty or non-compliance on the part of drivers in the through lane, it is difficult to speculate about whether appropriate opportunities for smooth and early merging really will routinely materialize. One interesting aspect of driver behavior at lane closures may complicate this cooperative merging. The large majority of drivers choose to decelerate and fall in behind another vehicle, rather than accelerate and move in ahead of another vehicle (Gardner and Rockwell, 1983). This may be due to a perceptual bias; equal size gaps appear smaller to the front, so the gap to the rear may appear safer. If, in response to an alternate merge sign, a driver in the through lane slows down to open an acceptable gap for a vehicle in the adjacent lane, the driver in the adjacent lane might be looking for an opportunity to merge behind the through vehicle. By slowing in an attempt to cooperate, the through vehicle might in fact be reducing the gap behind him, and delaying the opportunity for the merging vehicle to maneuver into the through lane. While this is speculative, it represents the kind of minor conflicts that might complicate smooth "alternate" merging even if drivers want to cooperate. If drastic slowing or abrupt lane changes occur, even if they are "alternate" merges, operational gains will not be fully realized.

In summary, it is questionable whether drivers will understand the sign meaning, know precisely what actions to take, be motivated to comply, and be able to make the desired maneuver in a manner that provides the intended operational and safety benefits.

Unknowns

There are several important "unknowns" which bear importantly on the potential of this device. First, the idea assumes a great deal about the motivations of the driving public. For example, the proposer states "Few vehicle operators enjoy the necessary delays caused by road construction and road maintenance.

If they are provided with a method which will minimize the inconvenience to some extent and provide a more logical and workable method of merging traffic, the majority will welcome this method." The degree to which the driving public will be cooperative is unknown.

A related question is how great the actual operational gains would be, and how sensitive this gain is to the degree of driver compliance. For example, if 5%, or 10%, of motorists do not comply, what will this do to the rate of traffic flow? What will it do traffic in each of the lanes, and how will this in turn affect the rate of subsequent compliance? If traffic behavior is very sensitive to the overall rate of compliance, then stable, positive effects may be difficult to gain.

Another unknown is whether this concept would lead to fewer, or more, traffic conflicts or accidents. As discussed earlier, there are ambiguities in how to respond to this sign, in addition to questions about willingness to comply. Merges at lane areas provide opportunities for vehicle conflicts, and in fact the objective of this sign concept is to reduce conflicts by specifying behavior.

However, if due to this sign, some drivers have expectancies about the behavior of other drivers which are then violated, it is conceivable that there may be <u>more</u> serious conflicts or actual accidents.

Design Considerations

Presuming the desirability of the general approach, there are a number of specific design considerations. One of these issues is the design of the sign graphics. Some graphic re-design is called for. The image provided in the original proposal does not appear to be successful in conveying the intended message. Some other graphic approach may be more successful, but this appears to be a difficult concept to symbolize. Even if the graphic concept were acceptable, there may be a legibility problem. Unfortunately, there is no accepted means for specifying the legibility of pictorial images, analogous to legibility criteria for letters and words. However, unlike most symbolic highway signs, the alternate merge sign does not contain any large, bold, simple graphic element that constitutes the primary part of the symbol. All of the graphic elements are small and composed of narrow elements. The small size of the arrows may be contrasted with the much larger arrow components in other work zone signs, such as the W1 series, W6-1, W6-3, or W12-1. Thus while the actual legibility distance is difficult to specify without empirical research, it is apparent that legibility will be poor relative to other signs. Add to this the generally reduced legibility of work zone signs as a group (because the brightness contrast of orange and black is less than for other color combinations), and the need for better graphic design becomes apparent. Of course, greater legibility can also be achieved by increasing the size of signs. This obviously has cost implications.

Another consideration in the use of this device has to do with sign placement. Proper placement is important but difficult to define without some clearer specification of the desired merge point. The beginning of the transition zone itself is not sufficient for defining a decision sight distance that will permit adequate time for the orderly advance merging that this device is intended to foster. The use of at least two alternate merge signs, as suggested in the submission, only confuses the issue further. If this concept is pursued further, the overall implementation design may have to consider means for better defining where driver actions are to take place, how this information may be conveyed (delineation, distance information on sign, etc.), and where signs ought to be placed.

Summary

The device as currently designed is unlikely to bring about the widespread orderly behavior that is required for "smoothing" the traffic flow at lane closures. There are fundamental questions about the effectiveness of the concept of the device itself, even if significant design improvements are made.

In some sense, we are not even certain of the intended status and purpose of the alternate merge sign. Is it intended to actually define the action required of each driver, as a regulatory sign does? If so, the required behavior needs to be greatly clarified. Is it intended simply as an encouragement for more polite and cooperative behavior? If so, the effectiveness of such admonitions must be questioned. Is it intended to inform drivers of the rules of the road? If so, this is probably not an appropriate function for a work zone sign.
The demands in terms of driver behavior remain similar to those currently required of a motorist at a lane closure: search for an adequate opportunity for a lane change, adjust speed to permit others to merge, monitor the behavior of others to avoid conflicts in competing for the same gaps, maintain adequate headway under dynamic traffic conditions, etc. Presumably the difference is that the behavior of other drivers will be more predictable and more cooperative. Whether this is true, and whether it leads to significant operational or safety benefits, remains questionable.

It would seem that the ultimate behavioral effectiveness of this approach would need to depend to a significant degree on an effective public education campaign and some fairly fundamental changes in driver behavior and in how motorists perceive right-of-way.

Based on the human factors evaluation this concept was abandoned.

Portable Sign and Stand

Human Factors Evaluation

Driver Task As Related to The Device

This device has little direct implication in terms of driver behavior, since it is an alternative construction for current signs. From the drivers perspective, the task is unchanged.

Benefits

There are actually two inter-related devices proposed. One is a portable sign stand adaptable to slopes, and the other is a neoprene cloth sign which fits the stand. Limitations to currently available signs and stands, including portable ones, include inability to use on extreme slopes and/or susceptibility to tipping in wind gusts. The sign-and-stand device proposed would purportedly permit a larger sign under certain conditions, would permit better sign placement under certain conditions, and would be less susceptible to tipping in wind gusts. Therefore driver detection and recognition of the sign should improve. Because the device is collapsible and easily portable, it is also reasonable to suppose that greater sign use may be encouraged.

Problems/Concerns With The Concept

There are no significant human factors issues associated with this basic concept.

Unknowns

The durability of the sign material and the legend printed on it is not apparent. The submitter claims that since neoprene does not scratch as easily as aluminum, it will retain the sign message longer. We do not know whether there may be fading after repeated use, or whether repeated folding could crease the face or cause damage. The integrity of the material itself under the abuse of field conditions, and any stress related to repeated mounting of the material on the sign stand, are not known. Therefore the ability of the sign to retain legibility under conditions of actual use will be important to determine.

Design Considerations

There are few human factors issues of significance associated with the design of this device. One concern is that the silk screened message on the neoprene background is of sufficient contrast, comparable to other sign types. We have no reason to presume it will not be. Also, neoprene apparently is available in various finishes (e.g. a matte "cloth", glossy), and these could impact legibility. For example, a glossy finish will suffer glare under many conditions (the photographs accompanying the original proposal show what appears to be a matte finish). Whatever material is chosen, the relative legibility of the message should be confirmed by photometric and/or psychophysical comparison with traditional signs.

Another design consideration is with the flatness and rigidity of the sign face when it has been mounted on the stand. There should not be substantial folds, sags, or creases in the material, and it should present a relatively flat surface oriented to the viewer. The material should not flap or vibrate in wind, since this would degrade legibility.

It is not clear whether the material is, or can be, retroreflective. Given the increased frequency of nighttime operations, the retroreflection problem must be carefully examined. If the material is not retroreflective, this limits the applicability of the signs to daytime applications, and may add to maintenance inventory problems.

A final set of concerns has to do with the human factors issues related to the mounting of the sign on the stand. It is difficult to comment directly on the current design, since the details are not clear. However, the mounting should be simple under field conditions and not liable to inappropriate "short cuts" in the field.

Summary

Presuming the concerns over graphic legibility are met, this device would permit conformation to better sign practice (size, location, height) under a wide range of site conditions. Therefore sign effectiveness could be improved in these settings. These benefits may be marginal in many situations, but could be important in others.

Description of Adopted Design

The design of this device was not altered from the original proposal. Plans and prototypes are available from the proposer Mr. Robert Fisher, Montana Department of Highways. The following description is taken from the original proposal.

Design Criteria

1. A sign stand which will stand on extreme slopes while maintaining a sign vertical to the roadway.

2. A sign stand allowing the use of 48" cloth signs as a standard sign on the primary and interstate system.

3. A sign stand which would hold the 48" sign in place in windy conditions.

4. A unit compact to store in limited space on maintenance trucks.

5. A sign of durable material to withstand tearing.

6. A sign with a design to allow attachment of a speed plate to the face.

Sign Stand

The sign stand folded is 36" long and 6" in diameter and weighs 40 pounds. In an unfolded position, the stand is 3' high, the legs extend 5' on both sides from the center of the sign. Construction is 1 1/4" X 1 1/4" X .083 tubing with 1" X 1" X 2' extension legs.

One unique characteristic of the sign stand is a rotating head which allows the sign to be in a vertical position when the stand is placed on a slope of up to 45°. The sign is adjusted to a vertical position by swivelling the rotating head and locking it into place.

Sign

The 48" X 48" sign is "neoprene" orange material with the legends silk-screened in black. We have seven different legends silk-screened including lane drop symbols, flagger symbol, road work ahead, right lane closed, left lane closed, and one lane closed. The upright support of the sign is 1" X 1" X 5 1/2' long tubing, bolted to the sign. The horizontal stanchion is 1" X 3/16" X 5 1/2' flexible fiberglass attached to the upright support by a center bolt. The horizontal stanchion fits into two pockets sewn to the back of the sign at the corners. Additional attachment is achieved by velcro straps attached to the back of the sign and wrapped around the horizontal bar at two points. The 1" tubing of the sign slips into the 1 1/4" tubing of the sign stand when in an upright position.

The 24" X 30" speed plate is white "neoprene" material with black silk-screened legend. A 1/8" X 1" X 28" piece of flexible fiberglass is attached to the top of the speed plate and a 3/8" X 1 1/4" x 24" length of rigid fiberglass is sewn into the bottom. The speed plate attaches to the 48" road work sign by inserting the 1" fiberglass into pockets sewn into the bottom one quarter of the sign face.

The entire assembly, (sign and stand) when fully erect, stands 8' high and provides the 1' minimum vertical clearance as provided by the MUTCD.

A 24" X 30" reduced speed ahead is made of white "neoprene" with a black silk-screened legend. The sign is attached to a 1" X 1" X 4' long vertical tubing. Two fiberglass cross pieces hold the sign rigid. The 1" vertical tubing slips into the 1 1/4" tubing of the sign stand. The sign and stand assembly, when fully erect, stands 5' high.

Truck Mounted Message Box

Human Factors Evaluation

Driver Task As Related To The Device

The purpose of the device is to alert approaching drivers to the presence and nature of mobile maintenance operations. For the device to be effective, it must be detected by the driver and be legible at an adequate distance. The meaning of the message must be comprehended. Once comprehended, the motorist must also understand the appropriate action to take. All of this must occur with adequate decision sight distance so that maneuvers may be safely made.

Benefits

The presumed benefits, relative to typical roadside signage, are (a) work crews will not be exposed to risk while deploying signs; (b) the truck-mounted sign will have greater perceived validity, since the sign stays "current with the work"; (c) the specificity of the message regarding the nature of the activity (e.g. "mowing") will enhance its believability and enable the motorist to confirm its validity.

Relative to typical variable message signs (VMS), the stated benefits are reduced cost, ease of use, low maintenance, and easy storage/transport.

Problems/Concerns With The Concept

The submission states that the sign will be "highly visible in all weather conditions." However the visibility and legibility distances are not known, and will certainly suffer in comparison to more typical variable message signs or arrow panels. The overall target size is small (18" by 6' face). The letters are only 8" in height, vs. 12" to 18" for typical VMS devices (thus 44%-66% normal size). Visibility and conspicuity are reduced by the lower mounting height (truck bed), as compared to variable message signs. The truck-mounted message is also likely to be more susceptible to glare. The flat plastic face, with limited shielding, may be contrasted with recessed or hooded lamps. Even with a sunshield overhang, low sunlight or headlights could produce significant veiling glare. Mounted near road level, the face panel would also be susceptible to dirt, spray,and debris which could scratch the surface.

The one-line display appears limited to about eight characters. For the example shown ("slowing") this is adequate, but for many of the other sorts of situations referred to (pavement repair, lane striping, litter pickup, accidents, flooded roads, etc.) it would not be adequate. Furthermore, the appropriate driver response is not well indicated by these messages. It is not clear whether greater caution, a lane change, a speed reduction, etc. is called for. More explicit messages about maneuvers, such as "merge left/right", are precluded by the limited number of characters.

Clearly this device is quite limited compared to other VMS devices, although it costs far less. The daytime effectiveness of the device, relative to ordinary truck-mounted passive signs, it not clear. While the illuminated message provides greater brightness, fixed signs provide color cues, shape coding, and potentially more effective target area. Because the proposed device changes its "variable" message by inserting and removing various message templates, there is no great advantage over fixed signs in terms of the inventory of devices required, or their storage and transport.

Unknowns

From a human factors perspective, the "unknowns" regarding this device are not so much in the area of driver behavior as they are in the target characteristics of the device in its final form. However, there does seem to be the inherent assumption that driver respect and response will be improved by explicitly describing the work activity in a VMS format, as opposed to a truck-mounted fixed sign, or some non-verbal display (e.g. arrow panel, flashing lights, etc.). This presumption is questionable. It also places faith in the ability of the motorist to translate the nature of the activity into a comprehension of the driving action he should take.

Design Considerations

The application of this device is not entirely clear. Is it intended to be mounted on a shadow vehicle, and serve as the sole warning and source of information about the work activity? If so, much greater design attention must be given to the conspicuity of the device. If there are additional devices (e.g. flashing lamps) mounted on the vehicle, or if more than one shadow vehicle is foreseen, or if fixed roadside signage is also to be used in conjunction with the device, this should be made explicit in order to evaluate the device.

The treatment of the interior of the message box may need further consideration. The proposer described it as polished aluminum, to provide a reflective surface to maximize light emission. However, there may be specular reflection from such a surface, such that the background lighting would appear uneven. Better results might be achieved with a white matte background.

In general, many limitations of the device are implicitly accepted as a trade-off for low cost and easy maintenance. These limitations include, for example, the restricted letter size, and the use of rear lighting rather than a lamp matrix. Therefore suggestions to redesign the device to get around the limitations of the design would generally defeat the submitter's original motivation to develop an inexpensive, usable TCD. If the limitations are accepted, more consideration must be given to human factors and traffic engineering considerations in the application of the device: the site factors and the other TCD's that might be used in conjunction with this devics

Summary

The potential effectiveness of this device may depend upon the applications. It may not be especially effective as the primary alerting device for the general spectrum of moving work zone activities. However, it might be applicable in certain settings (e.g. lower speeds) or in conjunction with other traffic control devices (e.g. an arrow panel) or vehicle-mounted displays.

The box is constructed from 3/4 inch marine plywood, except for the face panel which is a scratch resistant polycarbonate plastic, such as Lexon. The box is 18 inches high, 10 inches wide and 6 feet long. The precut message boards are made from 1/4" exterior A-B plywood, as are the individual letter templates and blanks. The box is attached to the tailgate of a dump truck used to transport material to a paving operation. The 5 high intensity lamps use a white bulb that reflects off of the polished aluminum interior surfaces and shines through the sign for approximately two seconds before flashing off for two seconds. The lamps are mounted in a rubber grommet for shock absorption.

Description of Adopted Design

The application of this device was altered slightly based on the human factors evaluation. The device will not replace most changeable message signs, but may be an effective device to be placed on the rear of vehicles that are transporting materials to a work site. Therefore, the design shown in Figure J-4 has been altered to read "Slowing". This message would flash as a vehicle approached a paving operation or other work area.

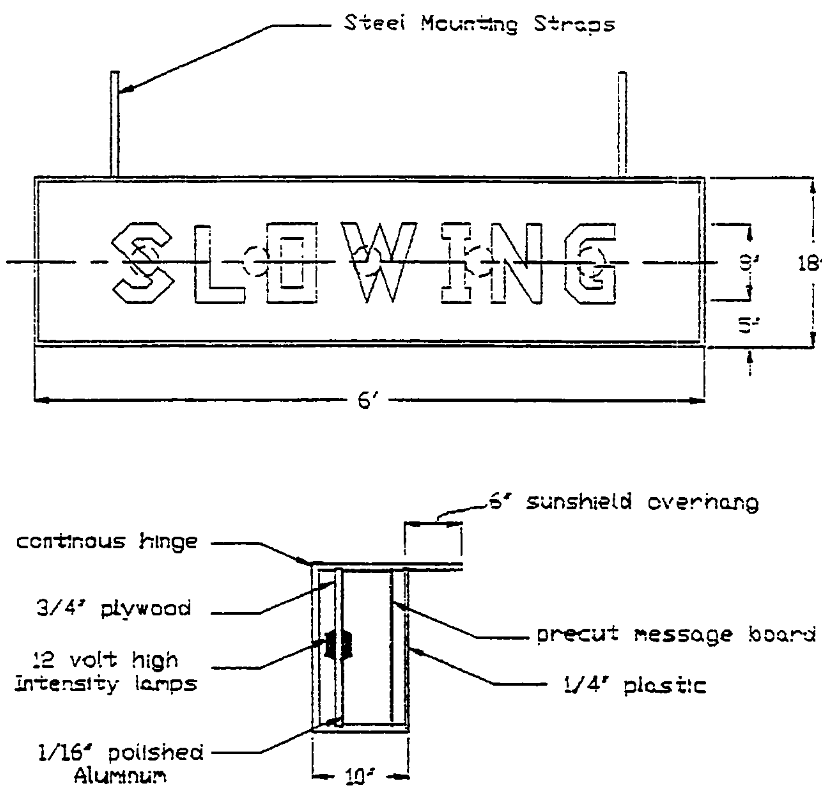


Figure J-4 - Truck Mounted Message Box

Appendix K

Automatic Guided Warning Vehicles

Introduction

The Automatic Guided Warning Vehicles (AGWV) are a series of driverless robot vehicles with signs attached to them to provide mobile advanced warning for mobile and slow moving highway maintenance operations. The AGWV are crashworthy and also serve as shadow vehicles. Because of the complex nature of this system, a feasibility study was mandated to determine if a reliable AGWV system could be designed and operated. The results of this study follow.

Many road crews tend to leave work zone signing behind as they move up the road. Motorists see the signs but no workers, and as a consequence become confused and disregard the signs. The practice in the long run erodes the credibility of work zone signing in the motoring public's eye. Some States use maintenance vehicles to carry signs, but these vehicles often get hit in the rear by traffic, injuring both worker and motorists. Shadow vehicles, also at the upstream end of work zones, are also often hit. The AGWV concept is designed to remedy this situation by forming a crashworthy, driverless moving sign caravan. Figure K-1 shows an AGWV vehicle. Arrow panels or variable message signs may also be used with the AGWV. A typical application consists of two AGWV upstream of a lead maintenance

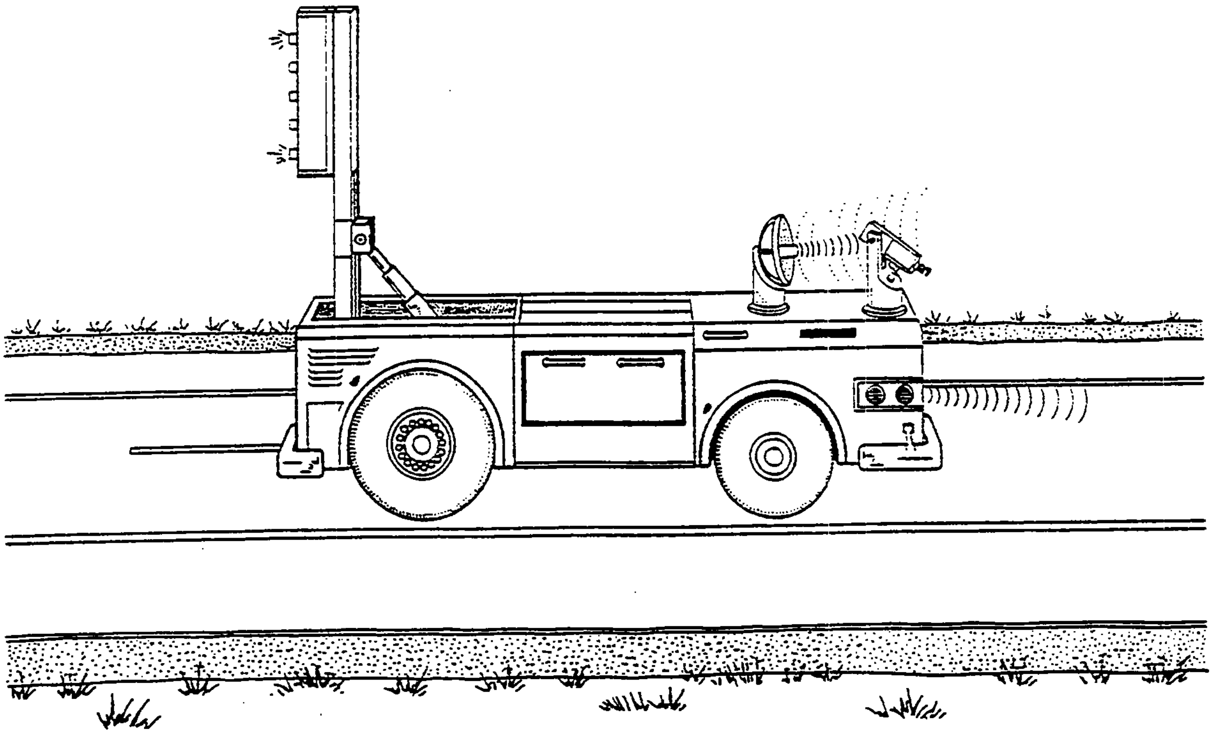


Figure K-1 - Automatic Guided Warning Vehicles vehicle in the advance warning and transition area. The AGWV would automatically follow the work crew down the road as they work and form the caravan. The rear most AGWV would be equipped with a truckmounted attenuator, and would serve as a shadow vehicle.

While the AGWV concept has high potential to eliminate injuries and deaths among maintenance workers, development of an actual working AGWV system will require the successful resolution of several technical issues.

The AGWV system must operate under a wide variety of adverse environmental conditions. Dust, humidity, heat, cold, rain, vibration, noise, and nearby traffic are just some of these. Also, the AGWV system must be able to operate at a relatively fast speed (15-20 mph), in order to keep up with maintenance operations. It must be able to stay behind the lead maintenance vehicle at a preset distance and between lane lines with a high degree of accuracy and reliability. Furthermore, it should employ some type of collision avoidance system to prevent the AGWV from hitting objects in it's path such as stopped vehicles. To accomplish these tasks, the AGWV needs a guidance and tracking system, as well as a collision avoidance system, all mounted on a crashworthy movable platform.

By far the most critical system of the AGWV is the guidance and tracking system. It is responsible for keeping the AGWV a preset distance behind the lead maintenance vehicle and between lane lines at all times. The original design competition proposal called for the lead maintenance vehicle to form a path by dispensing a series of retroreflective traffic cones on the roadway. The AGWV's would guide off of these cones using a laser based guidance system. The rearmost AGWV would then pick up the cones as it passed them. This approach was abandoned, however, since it has several flaws. First, both the cone dispensing vehicle and cone pickup vehicle would have to be very large and expensive in order to handle the number of cones necessary to cover any appreciable length of roadway. Also, the system would properly function only if the cones were properly positioned and upright. Unfortunately, traffic cones often get misaligned or knocked over, either by wind or passing vehicles. This would break the guidance path for the laser guidance system, effectively blinding the AGWV. An out-of-view pulse from the laser guidance system microprocessor would then have to be used to stop the AGWV so that it would not stray into nearby traffic lanes. The AGWV would then have to be retrieved either manually or by remote control and be set back on course. Either of these procedures would be both time-consuming and risky for the maintenance workers and passing motorists. Therefore, the project staff developed a more workable and reliable guidance approach that forms the heart of the AGWV concept.

Control and speed of the AGWV is governed by telemetry data automatically transmitted from the rear-most maintenance vehicle. Lateral placement of the AGWV is controlled by two independently operating overlapping systems. The first system is a microprocessor based data acquisition and telemetry system that records maintenance vehicle movements, such as wheel turns and tire rotations. This information is processed, then transmitted to the AGWV in the form of telemetry for guidance purposes. The second system is an video scanner that scans painted lane lines, digitizes the visual data by grayscale intensities, executes a pattern recognition routine to discern boundaries of the lane line in real time, and downloads this data to control servos that control lateral placement of AGWV. While video/optically guided vehicles are not an everyday occurrence, they are not unheard of, even in the transportation field. In 1981, British researchers reported on the successful development of a vehicle guidance system using automated scene analysis.[K1] This system uses image processing methods for determining the boundaries of a street, for detecting obstacles, and for measuring their distances relative to the driven vehicle. More recently, the French Public Works Administration sponsored the development of an automatic chip spreader that "sees" painted lines with optical readers and automatically advances, opens, and closes asphalt spray heads and chip spreaders.[K2] This system is currently operational. Each of the two AGWV critical systems are described in detail below.

System Description

The AGWV consists of a combination telemetry and video guidance and tracking system, and an ultrasonic collision avoidance system, all mounted on a small gas engine propelled platform. The AGWV would use video cameras to detect and follow the lane lines on the road surface, and a telemetry link to transmit and receive the necessary information to maintain set distances between the two vehicles and to maintain overall control of the AGWV. Figure K-2 shows the block diagram for the AGWV system.

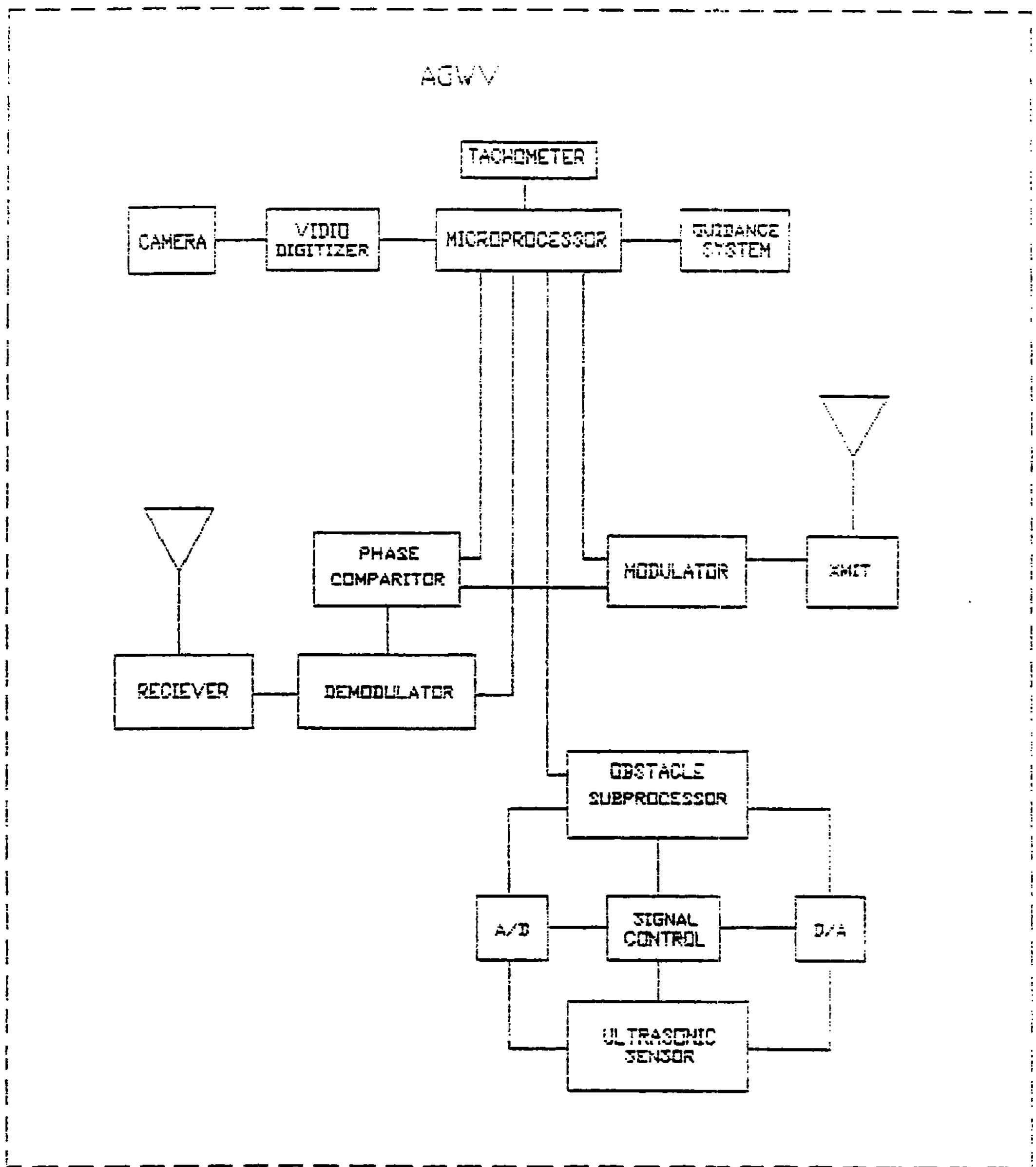


Figure K-2 - Block Diagram for AGWV System

Telemetry

A tachometer would be mounted on the maintenance vehicle. The output of the tachometer would be used to determine the number of feet traveled which would be used in the algorithm determining the direction of travel. The tachometer would also be used for speed control. The communications link would also contain the ability to tell the AGWV when to start keeping pace with the lead vehicle and when to continue with a steady speed in order to catch up to the lead vehicle at the end of the day. The interval between the two vehicles would be accomplished by sending an FM signal from the maintenance vehicle to the AGWV.

This FM signal would be demodulated and converted to a drive signal that would set the speed for the AGWV. A second signal would be generated within the AGWV that would be an indicator of it's true speed. This signal would be compared to the demodulated FM signal from the maintenance vehicle. This would give a phase difference that would be converted to an error signal causing the AGWV to change speed. This method would be able to maintain an interval between two vehicles of some fixed interval plus or minus a few feet. The error in maintaining a fixed interval would be determined by the value of the modulating frequency.

The telemetry unit is a complex computer communication and data acquisition unit which will require climate control. Air filters and air conditioning will be needed for this unit to operate efficiently. Electronic noise limiters will be incorporated into the system to help eliminate interference problems from mobile phones, CB's, and overhead structures.

Video

The video segment of the AGWV guidance system would consist of a camera mounted on the front of the vehicle and mounted in a manner parallel to the direction of travel and mounted high enough to have a sufficiently large field of view to encompass enough lane lines to be accurately guided.

The output of the camera would be digitized and the position of the lane line within the frame would determine the amount the AGWV would have to move in order for the image of the lane line to be properly positioned within the frame. Image position tolerances would have to be generous enough to allow for vibration of the camera relative to the roadway. An algorithm would be written that would use the result of 30 or 40 frames to determine the general direction of the lane lines and then the result of the algorithm would be used to send a signal to the steering mechanism that would correct the direction of the AGWV in order to maintain the image of the lane line in the center of the frame. The AGWV would continue along a path as determined by the algorithm and would maintain this path between lane lines. If the AGWV traversed a predetermined number of feet without seeing a new lane line the AGWV would stop its forward travel and send out an alarm signal.

Any change in the direction of travel would be corrected using an output that is filtered by the algorithm and would require the sum of at least three broken roadway lane lines or 100 feet of solid lane line to determine the basic direction of travel. This output would then be applied to the guide wheel that would only be allowed to change one-third of a degree per update. This update would be made every foot.

Systems exist for frame digitization of the incoming data at a 30 Hz rate, at that frame speed a forward speed of 15 mph should be possible.

The video system needs to be safeguarded from dirt, water, and bright ambient light. In the case of excess dirt a filter or shield will be used to protect the unit. In the case of water a dry shield will be used. A polarized filter will be used to help screen out bright ambient light and reflection.

Collision Avoidance

The collision avoidance is an ultrasonic sensory system which scans ahead of the moving vehicle detecting obstacles in the vehicles path.

The sensory units are ultrasonic sensors sending out a high frequency signal and timing signal return. Based on return time obstacles can be detected.

The digital to analog converter takes the signal emitted by the signal controller and creates the sensor signal. The analog to digital converter digitizes the conditioned return signal so that it can be processed by the obstacle subprocessor.

The signal controller produces the digitized signal, and conditions the incoming signal with a filtering system.

The obstacle subprocessor checks the signal for obstacle detection and outputs a set of control flags alerting the CPU of it's status.

The CPU checks status from the obstacle subprocessor and ties the information in for vehicle control use. If there is an obstacle detected then the vehicle stops. If there is no obstacle detected then the CPU defers to the information coming in from the video system and the telemetry system.

Operating Procedure

A typical day of operating the AGWV would be to tow the AGWV to the work area, initialize the system, operate the system during the day, power down the system and tow away the AGWV. The AGWV would serve as either a robot sign caravan, a shadow vehicle, or both.

To initialize the system the operator would turn on power to the AGWV and boot the system. This would be accomplished on the shoulder. The lead vehicle would then separate from the AGWV some desired number of feet and thru the telemetry system tell the AGWV to begin tracking the lead vehicle at the same pace as the lead vehicle. Once this pattern and distance is established, the lead vehicle and AGWV would simultaneously pull off the shoulder and into the working lane. Guidance of the AGWV may require human remote control for this step to ensure the AGWV does not pull in front of oncoming traffic. The AGWV would continue to follow the lead vehicle at the speed of the lead vehicle. To retrieve the AGWV, a command is issued by the lead vehicle telling the AGWV to pull to the shoulder, continue forward at speed until it approaches the lead vehicle, where the AGWV is powered down and towed away. The procedure for coordinating two AGWV's would be similar to this, except that the upstream AGWV would probably remain on the shoulder, and also the two AGWV's would be at different distances from the lead vehicle.

Conclusions

Based on the results of this study, a reliable AGWV system as described in this appendix is technically feasible. It is therefore recommended that development of this system continue in project H-109.

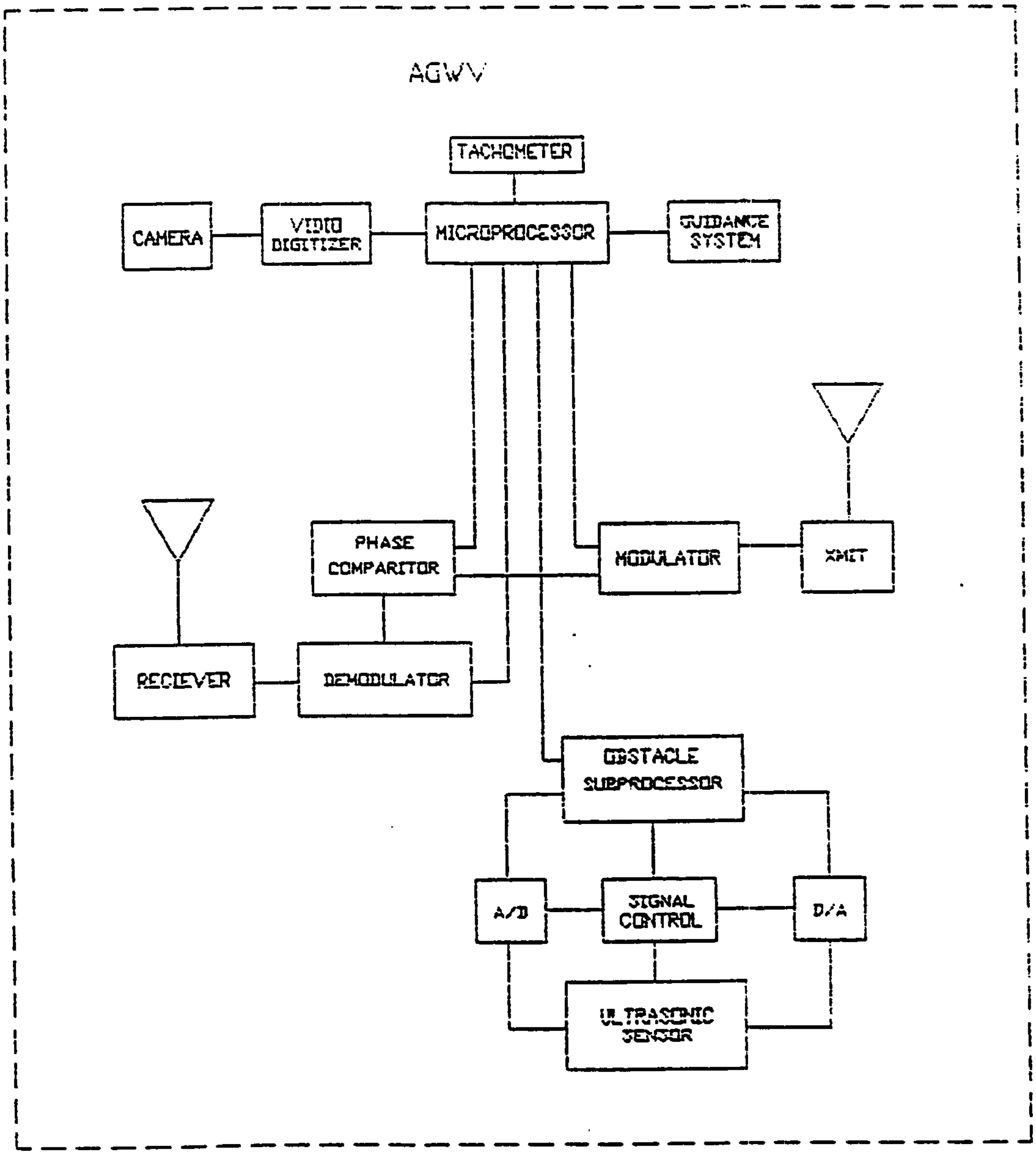


Figure K-2 — Block Diagram for AGWV System