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Presentations from the 9th Equipment Management Workshop

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PRESENTATIONS FROM THE 9TH EQUIPMENT MANAGEMENT WORKSHOP

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FOREWORD

Equipment managers in public and private organizations are responsible for all aspects of providing a diversified fleet of motorized equipment. Factors of concern to equipment managers include cost control, preventive maintenance, repair, shop productivity, employee training and motivation, equipment replacement decisions, inventory control, commercial drivers license requirements, alternative fuel engines, environmental safety, privatization, electronically controlled diesel engines, and other related topics. Nine Equipment Management Workshops have been conducted since 1976 to provide a continuing forum for the exchange of new ideas and developments in maintenance and management of equipment fleets.

The Ninth Equipment Management Workshop was co-sponsored by the Transportation Research Board Committee on Equipment Maintenance and the North Carolina Department of Transportation in Research Triangle Park, North Carolina, June 15-18, 1992. The proceedings of this Workshop are included in this *Circular* and structured around five topics:

- Equipment Standardization
- Equipment Research
- Environmental Issues
- New Technology
- Human Resources and Equipment Management

Planning is ongoing for the 10th Equipment Management Workshop to be held in Portland, Oregon, July 31 - August 3, 1994.

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SECTION I EQUIPMENT STANDARDIZATION

EQUIPMENT SPECIFICATIONS GUIDE

Arlen T. Swenson, *John Deere National Sales*

I have had the pleasure during the past twenty years of working with a variety of customers and end-users in the governmental industry. It has always been interesting to me during that work to note the seemingly countless different ways individual agencies and highway departments approach the same task. In particular, the variation in procurement specifications can quickly tempt one to conclude that agencies never exchange information. Certainly that assumption isn't true. However, the whole area of procurement specifications and the need for some form of equipment standardization recently lead the Transportation Research Board (TRB) Committee A3C08, *Maintenance Equipment*, to investigate the question, "Isn't there a better way to do the job?"

Approximately two years ago, the Design Standards Subcommittee of TRB Committee A3C08 began a study of how different state highway departments and individual governmental agencies procured equipment. The results of that work were published in October 1991 in *Transportation Research Circular 381*, "How To Develop and Use Equipment Performance Specifications." Although many techniques are used in procuring equipment, it was discovered that agencies who were satisfied with their acquired products all consistently included five similar steps in their acquisition method. Conversely, agencies who were not satisfied with the results of their acquisition method normally missed one, two, or even three of the five steps.

The *Circular* details the Five Easy Steps To Successful Specification Writing and how they can be applied to developing a more successful acquisition program. The key steps reviewed include:

1. Understanding Job Requirements
2. Determining What's Most Important
3. Evaluate Equipment On-The-Job
4. Clearly Stating What Is To Be Purchased
5. Identify The Bid Award Criteria

The *Circular* also provides examples of specification wording for items such as product support and samples of performance specification writing that helps clarify the overall machine and supplier performance required by an agency and not simply the technical specifications of the equipment. The reaction from readers has been very positive and has helped some, both private and public, to improve their procurement methods. For those interested in taking a closer look at the *Circular*, copies are available from TRB.

Does this mean you now have all the answers? Certainly, the *Circular* fills an important need in being a good reference guide, but it can't answer every situation. In addition, printed material can become quickly dated in this rapidly changing technological world. Are there other ways to stay current and up-to-date? You bet! Electronic spread sheets and personal computers are certainly nothing new, but the application of user friendly, easily updatable, and inexpensive software bases to the world of specification writing adds some new dimensions you might enjoy seeing.

Various suppliers and manufacturers are continually working on better ways to help the electronic communication process and I would like to share one new development with you at this time. This particular computer program is available through John Deere, however, other manufacturers also have electronic spread sheet programs that can do similar functions. This particular program, however, is unique in its interaction with the user. For example, the program starts by offering a menu of subjects. Selecting from the menu quickly brings the user to appropriate areas of interest without the need of a detailed manual or a deep understanding of computers. Details on machine features, performance specifications, value analysis, acquisition choices, product support, and comparative specifications are quickly available at the touch of a key. Even better news, the information is updated three times yearly. Here's a possible sequence a user of the program might go through when investigating a backhoe loader:

- Selects Performance Specifications
- Selects Backhoe Loaders
- Reviews Proposed Specifications
- Reviews Specifications Compared to Various Manufacturers
- Selects Features & Benefits
- Reviews Different Areas of Machine
- Reviews Standard Equipment
- Reviews Optional Equipment
- Selects Acquisition Choices
- Reviews Leasing, Renting & Other Options
- Reviews Warranty & Extended Coverage Options
- Performs a Value Analysis Comparison

During the process, the user can refer to a word glossary for clarification of terms and can print information. For a copy of the *Circular* and/or the software program for specification writing contact the author at John Deere National Sales, 400 - 19th Street, Moline, Illinois 61265-1373.

SPECIFICATION COMPARISON : 29,000 TO 32,000 GVW CAB CHASSIS 7 CUBIC YARD WATER LEVEL DUMP BODY

Wayne M. Layman, P.E., (Retired) *Mississippi State Highway Department*

Standardization of equipment used for maintenance of highways by the states, provinces, and territories has been discussed for several years as a method to achieve lower initial cost due to volume purchases and to provide industry with a standard model to bid. Fleet standardization was one of the main topics at the first meeting of the Southeastern State Equipment Managers in 1987 in Montgomery, Alabama. The southeastern member states decided the best approach to fleet standardization was to investigate what the states were actually purchasing. To do this, each state agreed to do a specification comparison of a particular item of equipment and report on the results at the annual Equipment Managers Meeting. The information received from the member states revealed that we were close to standardization for horsepower, weight, and dimensions with variations for optional equipment required by each state. This I think this is due to the similarity in industry manufacturing models of equipment, federal regulations controlling what industry can manufacture, and competition that provides the states with a common base product or item of equipment from which they can specify. It is unlikely that specification writers minds run along the same parallels as much as they are specifying what is available on the market.

I chose twelve (12) components of a 29,000 to 32,000 GVW, 7 cubic yard dump truck for comparison. I had to read some specifications four times before I found where the paint color or axle capacity or other components were hidden in the specification. I feel that industry contributes to this confusion by not listing their truck components in the same order. Trying to interpret their data books these days is a challenge. Requests for specifications were mailed to 61 states, provinces, and territories. Forty-seven (47) replies (77%) were received. A summary of the specification comparison is given below by component.

GVW AND CAB-AXLE DIMENSION

3 specified less than 29,000 GVW	6%
19 specified 29,000 to 32,000 GVW	40%
21 specified more than 32,000 GVW	44%
3 did not specify GVW	6%
2 furnished only body specs	4%
48	100%

In reviewing the GVW's specified, the three less than 29,000 GVW did not use the truck for snow plowing and three of those specifying over 32,000 GVW (Alabama, Florida, and Hawaii) were not in snow states. Of the 19 in the 29,000 to 32,000 GVW range, 11 were specified in states that have little or now snowfall. In summation, the specs indicate that the GVW and the body size specified are determined by the combination of use of snowplows, and sand or slag spreaders.

Of the Cab-Axle (C.A.) specified, six were 72 inches, 22 were 84 inches, one was 96 inches, eight were 102 inches, one was 108 inches, two were 120 inches, one was 138 inches, and seven did not specify a C.A. dimension. The C.A. dimension has a direct correlation to the size of the dump body desired.

ENGINE

Type

43 specified diesel	90%
1 specified gasoline	2%
2 did not specify type	4%
2 furnished only body specs	4%
48	100%

Horsepower

Diesel

1 specified 165 HP	2%
2 specified 170 HP	4%
1 specified 175 HP	2%
1 specified 176 HP	2%
1 specified 180 HP	2%
6 specified 185 HP	13%
1 specified 190 HP	2%
1 specified 195 HP	2%
3 specified 200 HP	7%
3 specified 205 HP	7%
10 specified 210 HP	21%
2 specified 220 HP	4%
1 specified 227 HP	2%
1 specified 230 HP	2%
2 specified 235 HP	4%
4 specified 240 HP	8%
1 specified 260 HP	2%
1 specified 270 HP	2%
1 specified 325 HP	2%
1 specified 125 KW	2%
1 did not specify HP	4%
2 furnished only dump body spec	4%

Gasoline

1 specified 231 HP	2%
48	100%

From the tabulation of horsepower specified, industry will meet or exceed just about any horsepower specified. The torque range ran from nothing specified by 11 to a high of 1250 ft-lbs. In matching engines and transmissions, torque is more important than horsepower and controls the size transmission required.

AXLE CAPACITY AND MAXIMUM SPEED

22 axle cap. specified equaled GVW specified	46%
19 axle cap. specified exceeded GVW specified	40%
5 did not specify axle cap. or GVW capacity	10%
2 furnished only dump body specs	4%
48	100%

In order for industry to meet federal regulations in certifying GVW ratings, tires, wheels, axles, suspension and frame must be considered. You must have axle capacities at least the same as GVW specified. In most cases where axle capacities exceed specified GVW, the tires are the controlling factor that establishes the GVW rating. Thirty of the specs received specified maximum speed in a range of 55 to 66 mph. A few of the states are still specifying axle ratios but I found it a costly way that can get a spec writer in trouble.

BRAKES

43 specified air	90%
3 specified hydraulic	6%
2 furnished only dump body specs	4%
48	100%

In reading trade magazines, I note that some manufacturers are going to air over hydraulic brake systems.

CAB

43 specified conventional cab tilt hood	90%
2 specified conventional cab	4%
1 did not specify	2%
2 specified only dump body specs	4%
48	100%

Of the specs requiring tilt hood, 19 specified fixed grills and the rest specified butterfly hood, butterfly access or alligator style.

FRAME

Section Modulus (SM), Yield Strength (PSI) & Resisting Bending Moment (RBM)

1 specified SM	2%
5 specified SM & PSI	10%
9 specified SM & RBM	19%
7 specified PSI & RBM	15%
4 specified SM, PSI & RBM	8%
15 specified RBM	32%
1 specified PSI	2%
1 could not interpret	2%
2 did not specify	4%
2 furnished only dump body specs	4%
2 specified to meet GVW	2%
48	100%

Section Modulus Specified (SM), cubic inch

12.53, 13.42, 13.50, 13.60, 14.00, 15.00, 15.00-18.00, 15.90, 17.60, 18.00, 20.00, 23.30, 27.75, 30.00

Yield Strength Specified (PSI), pounds per square inch

50,000; 110,000

Resisting Bending Moment Specified (RBM)

670,000; 850,000; 852,000; 900,000; 915,000; 916,000; 1,000,000; 1,100,000; 1,170,000; 1,180,000; 1,300,000; 1,378,000; 1,400,000; 1,500,000; 1,600,000; 1,700,000; 1,749,000; 2,000,000; 2,290,000: 2,500,000; 2,563,000

These listed variations indicate to me that each spec writer is specifying a certain frame. I have always tried to specify the heaviest frame I could get on the model truck that met GVW requirements.

TRANSMISSION

13 specified automatic	27%
24 specified manual	50%
2 specified automatic-manual optional	4%
7 specified manual-automatic optional	15%
2 furnished only dump body specs	4%
48	100%

The percentages indicate that 31% specify automatic transmissions with 15% not being convinced that automatics are the way to go. As indicated by the spec comparison, the ratio of automatic to manual is about

50/50. Personally, I think automatic is the only way to go.

TIRES

1 specified 10:00x20 - 12-ply	2%
1 specified 11:00x20 - 14-ply	2%
1 specified 10R20 - 14-ply	2%
2 specified 10R22.5 - 12-ply	4%
2 specified 10R22.5 - 12-ply F - 14-ply R	4%
19 specified 11R22.5 - 14-ply	40%
9 specified 11R22.5 - 16-ply	19%
1 specified 11R22.5 - 14-ply F - 16-ply R	2%
3 specified 11R22.5 - 16-ply F - 14-ply R	7%
1 specified 12R22.5 - not specified	2%
1 specified 12R22.5 - 16-ply	2%
1 specified 275/80R22.5 - 14-ply	2%
1 specified 315/80R22.5 - 18-ply front 11R22.5 - 16-ply rear	2%
1 specified 315/80R22.5 - J front 12R22.5 - 16-ply rear	2%
1 specified 315/80R22.5 - J front 11E22.5 - rear	2%
1 specified first line quality radial-14ply	4%
2 furnished only dump body specs	4%
48	100%

Specifications indicate that all but two (2) states are using radials. Various combination of tires, sizes, and plys are specified as a result of individual use of trucks, etc. Snowplows require heavy tires on the front - others are specified only to meet GVW requirements of the truck.

WHEELS

27 specified disc	56%
18 specified cast spoke	38%
1 could not interpret	2%
2 furnished only dump body specs	4%
48	100%

Fifty-six percent of the spec writers are specifying disc wheels. If you've ever tried to true a rim on a spoke wheel with a piece of chalk and a jack, outside in 99° degree heat, you would never again specify a spoke wheel. They are a standard on most trucks and therefore cheaper but I'm sure the labor cost of maintenance quickly exceeds any initial savings derived.

DUMP BODY
CUBIC YARD WATER LEVEL CAPACITY

1 specified 3.00 Cu. Yd. W/L	2%
1 specified 3.50 Cu. Yd. W/L	2%
10 specified 4.00 Cu. Yd. W/L	21%
1 specified 4.73 Cu. Yd. W/L	2%
18 specified 5.00 Cu. Yd. W/L	38%
3 specified 6.00 Cu. Yd. W/L	6%
2 specified 6.50 Cu. Yd. W/L	4%
5 specified 7.00 Cu. Yd. W/L	11%
2 specified 8.00 Cu. Yd. W/L	4%
1 specified 10.42 Cu. Yd. W/L	2%
1 specified 3660 mm	2%
3 did not specify size	6%
48	100%

Specifications indicate that snow states use a smaller capacity dump body to prevent overloading the truck when it has a snowplow. Specs also indicate the odd capacities are from states designing their own body. One spec calls for a stainless steel tail gate, another requires an aluminum tail gate, for ease of removal I guess, and one specifies corten steel. Most snow states require rust proofing.

CENTRAL HYDRAULICS

27 specified central hydraulics	56%
20 did not specify central hydraulics	42%
1 could not interpret	2%
48	100%

All of the states specifying central hydraulics receive their winter rains as snow, freezing rain or sleet.

PAINT COLOR

14 specified orange	29%
16 specified yellow	34%
2 specified green	4%
4 specified white	8%
1 specified state buff	2%
1 specified white/blue body	2%
2 specified yellow/black body	4%
3 specified yellow-black hood	7%
1 specified orange-black hood	2%
1 specified manufacturers standard color	2%
1 to be specified after award of bid	4%
2 not specified	4%
48	100%

This is one that gives industry fits. It does not appear there is any two states that accept the same color unless it's manufacturers standard colors. The general opinion is that maintenance workers need equipment painted a color to help identify a work zone or zone of caution. I think there should be uniformity whatever the color chosen.

NUMBER PAGES OF SPECIFICATIONS

3 had	3 pages
2 had	4 pages
1 had	5 pages
2 had	6 pages
3 had	7 pages
2 had	8 pages
2 had	9 pages
1 had	12 pages
1 had	13 pages
2 had	14 pages
2 had	15 pages
2 had	16 pages
2 had	17 pages
2 had	18 pages
1 had	20 pages
1 had	21 pages
1 had	22 pages
2 had	23 pages
2 had	31 pages
2 had	32 pages
1 had	34 pages
1 had	42 pages
1 had	43 pages
1 had	45 pages
1 had	46 pages
1 had	64 pages
1 had	67 pages
1 had	75 pages
1 had	89 pages
1 had	158 pages
2 had	16 pages dump body specs only

CONCLUSION

In reviewing the specs, it is evident that states requiring snowplows, central hydraulic system sanders and spreaders have to have more pages of specs than southern and Sun Belt states. The large number of pages also indicates to me the spec writer is trying to be assured he is delivered a truck that meets his requirements totally because he has no control over the award of bids or he has been burnt in the past. Not having control over the award of a bid is aggravating, getting burnt is a learning experience. If industry was not trying to get a price advantage, a truck spec could only consist of 7 to 10 lines.

We each have to spec what we think best fits our needs and within the confines of what industry is willing to build. We can't get standard within the six Districts in Mississippi - to be standardized in North America is a dream.

STANDARDIZATION OF SPREADER SPECIFICATIONS: "THE ULTIMATE SPREADER"

Robert L. Henderson, (Retired), *Swenson Spreader Company*

Over the years much information has been published concerning the writing of specifications. Technical specifications for any type of mechanical equipment can go into great detail. This type of equipment is generally called a turn-key package and may be classified as a front end loader, a backhoe, a motor grader, or countless other variations on these themes. Snow and ice control vehicles, on the other hand, can be bid as a turn-key package or as individual components that are assembled by the end user. I would like to caution each of you to be as detailed in writing the specification for the individual components (i.e. dump body, central hydraulic system, plow and spreader) as you are for the carrier vehicle.

Over the past 17 years with my company it has occurred to me that I have seen no two state specifications exactly the same. As a matter of fact I cannot get any states to agree whether they should be using tailgate spreaders, V-box spreaders (hopper type) or a combination of both. In that same period of time, it has occurred to me that I have fallen into the habit of beginning many of my speeches with the dictionary definition. This really is not a bad habit, since it brings the subject of this discussion into focus almost immediately.

A spreader, as defined in Webster's Dictionary is "an implement for scattering material." This really shouldn't be too complicated a problem -- or is it? This is a tailgate spreader and this is a hopper spreader and this is wide conveyer spreader. As you noticed, all these spreaders are pretty basic - there are no options on any of them and they will all perform the job they were intended to do. That is, they will all scatter material satisfactorily. However, the problem is far more complicated than this!

If you remember the cars that came out of Detroit in the late fifties, you also will remember some monstrosities that they created. This is because they took the car design out of the hands of the realistic designers and turned them over to the "artistic designers." This led to the very high three taillight fins on the back of the cars, eyebrows over the headlights, massive chrome grilles and automobiles that rusted out in less than a year. This corrosion was due to all the built-in pockets that held dirt that never dried. I'm sure that some of these "artistic designers" were later hired as specification engineers for governmental agencies. I'm not saying that special spreaders do not serve some very specific requirements but rather, that these special spreaders are very difficult and time consuming to build and are very expensive. All spreader manufacturers face the same problems building specials. Let me give you some examples:

- This is a stainless steel airport spreader - it has dry material spreading capacity with automatic controls - there are two 125 gallon liquid storage tanks for ethylene glycol or clear liquid to be sprayed on the dry prilled urea or a urea sand mixture with automatic spray controls. There are bin level indicators and liquid level indicators in addition to a roll up tarp that covers the screens and the loaded material.

- This spreader is a large capacity (17 cubic yards) spreader used primarily for city work. As an ex-city of Chicago employee, I can assure you that once these trucks leave the salt stock pile, they must be kept on the street. Because of traffic conditions, it becomes almost impossible to get them back to reload. Therefore, it is imperative that they have enough material to finish their assigned routes. Some features on this spreader are clean out doors, a swing out back gate, reversing valve, special light package and belt over chain.

- This next spreader is intended for use in the mountains and has special built-in exhaust heaters for the sides of the V-box, an air deflector for clearing snow off the back of the truck, a special lighting package, a special bumper for protecting the spinner and mars lights on both ends of the spreader.

Earlier, I had mentioned that building an implement to scatter material "does not sound too complicated." Let's see how complicated it is! As a standard, we produce 10 lengths (8 through 17 ft.); 4 heights (48 through 66 inches); 4 different raw materials (carbon, corten, 304 ss, 409 ss); 4 material gauges (7 ga., 10 ga., 10 ga. ss, 12 ga. ss) and 4 different design styles (6 tooth, 9 tooth, replaceable chain shields, stainless steel) for a possible 1280 V-box weldments. Now, if you add other design changes, such as sloped fronts for a doghouse lift cylinder, spring loaded idlers, swing out rear gates or special widths you can, through geometric progression, come up with the possibility of 240,000 combinations of V-box weldments. Just when we think we have built every possible one of these combination, somebody will come up a new one.

Now that you've seen a sample of our more exotic spreaders, I'd like to take this opportunity to introduce you to "the ultimate spreader." I don't want you to think this spreader is too far out of the realm of possibility. You have seen many similar spreaders. My chief engineer cautioned me to be careful with this subject,

since somebody may try to order one. Let's start with the chain oiler. Of course, there is no such animal as a rust sensing chain oiler but there are manual chain oilers and we also have provided chain oilers with an electric on-off solenoid switch. We also provide extended grease zerks for bearings. Next, we've come up with retractable top screens. We haven't perfected this idea yet but nobody has specified them as yet. I know a 2 million candlepower strobe seems a little overdone, however, you would not believe some of the lighting specifications that we receive. We have had lighting packages with 26 lights on the back of the spreader alone.

I would now like to discuss a few more options that have been developed over the years. We currently list more than 30 V-box options. It is not up to the manufacturer to know what your needs are or to be the judge of the best type of equipment to fill your requirements. You know your terrain, you know your material (sand, sand and salt or straight salt), you know your personnel and above all, you know the prevailing type of weather in your area better than any outside expert. In other words, you have all the information that is needed to specify the type of equipment you want and need.

Now for the real heresy--most of the main line spreader manufacturers build reliable, solid, well engineered products. Contrary to the opinion of many public works officials, we are not out to get away with anything we can. Most of us have variations in the components we use and there are differences in manufacturing techniques, but in the end, they all perform just about the same. That is, we all create a unit that is designed to scatter some type of granular material. If there are differences in spreading patterns, they are more than likely due to differences in the truck's central hydraulic system rather than the way the spreader is built. We have had contracts where we have supplied a large number of spreaders for brand new trucks. All the hydraulic components are the same and they have been installed by the same hydraulic installer. The spreaders have all been built at the same time and yet, many of the spread patterns and calibration rates can vary, even when the control valves on the two different vehicles are set on the same settings. I would now like to ask you this question--What do you want?

This brings us back to the beginning, and the beginning is specifications. Specifications are a set of requirements issued by the user that all bidders are expected to conform to. Specifications explain, sometime in great detail and sometime in very limited detail, "what you want." I believe specification engineers should have a "hands on" feeling for the equipment they want. I also feel that specification engineers should sit down and listen to the using department's wants and needs and I'm not talking about just department heads. They also should talk to the operators who have to use the equipment and the mechanics who have to service it. Too often, I've heard of an agency getting a brand new piece of equipment and the first thing the mechanics do is take a part off and throw it away. Why was that part specified? It's costing you extra dollars. Another problem I have with governmental agencies, is the lack of trust you have in your supplies. We have not survived in this business for over 50 years by delivering junk. If you have a problem, or there is a questionable clause in the specifications, we generally will call the agency. It is to our advantage and yours, to solve that problem before we build the equipment rather than to have you reject it when it's delivered. We would rather "do it right the first time." You will only get what you specify---no more, no less.

We, the manufacturers, cannot survive in a low bid business by providing extras you only thought you were going to get. If you require a specific part, use proprietary (trade) names. Courts have upheld this practice when used by an agency for the purpose of standardization. Be very careful of or equal clauses. Your definition of or equal and my definition of or equal can differ dramatically. Also, be very careful of some of these exotic paint finishes. As soon as these special finishes are damaged and moisture can get through it, rust will begin to undercut the finish. If you have problems with corrosion, I would suggest that you consider stainless steel. Although this product is initially more expensive, maintenance of stainless steel spreaders is almost nonexistent. When one considers sandblasting and repainting at current labor costs, stainless steel is certainly a viable alternative.

Now, a few words about enforcement. If it's what you want, insist that you get it. Don't go through all the headaches of writing a specification and then decide after the contract is awarded that you can do without what you specified. That is unfair to all the other bidders on that contract. I don't mind responding to any bid request as long as I know all the bidders are playing by the same set of rules.

In summary, review your specifications and ask yourself if this is really "what you want." If you have any specific questions about options, call and ask a manufacturer about that option. If you talk to their service manager, I'm sure he can tell you about the cost and reliability of that particular option. Most main line manufacturers have been in the business long enough to have seen most of these special features. There is no standardization in the spreader business, however, we are dealing with "an implement to scatter materials" and the basic design has remained unchanged for many years. Any of us will build "what you want" but it's up to you to make sure you want it.

COMPARISON OF EQUIPMENT PAINT SPECIFICATIONS (Outline)

Glenn R. Hagler, *Texas Department of Transportation*

INTRODUCTION

For years, government entities and companies in the private sector have made a concerted effort to determine what paint specifications should say and require. Visibility and the environment are two areas that must be considered when specifying fleet paint colors.

- Safety/Visibility - Safety and visibility go hand in hand. Imagine yourself as a highway patrolman arriving at the scene of a rear-end collision between a truck and another motor vehicle. The driver of the motor vehicle approaches and confesses: "I honestly didn't see that truck, officer," or "I didn't see that truck in time to stop!" Why didn't the driver see the truck? A number of factors may have been operating to impair visibility, but let us consider one important factor--the vehicle's coloring.

- Environment/Federal Guidelines (EPA,OSHA) - The environment is a hot topic right now. Government is being asked to account for its policies that affect what the public views as its natural heritage. Our image and our responsibility to make environmentally sensitive decisions are intertwined as are safety and visibility when considering paint colors.
  - By 1981, there was considerable concern in the paint and manufacturing industry about the use of paints containing lead. The Consumer Product Safety Commission (CPSC) declared paints containing more than 0.06% lead were hazardous and banned their use in the manufacture of toys and furniture.
  - Subsequently, the Environmental Protection Agency (EPA) and the Occupational Safety and Health Administration (OSHA) promulgated strict rules for application of leaded paints on manufactured goods. What are the hazards related to the use of leaded paints?
    - Application - drift, inhalation (human factor, environment)
    - Paint Containers - disposal, cleanup (human factor, environment)
    - Body Work - cleanup, inhalation (human factor, environment)
    - Trickle-down - eventually gets into food chain. Recent studies prove an alarming percentage of school children have elevated levels of lead in their bloodstreams.
  - The results: Beginning in 1981, manufacturers began to voice their concern about meeting specific color requirements in view of the newer, stricter rules. Some manufacturers did away with usage of leaded paint altogether, rather than modify existing facilities.
  - Facing imminent increased regulations from the Michigan OSHA (MIOSHA), clear-coat painting systems were introduced by automotive manufacturers beginning with Chrysler in 1986, followed by Ford and General Motors in 1987. Light and medium duty trucks would also eventually follow.

VARIOUS STATES' FLEET PAINT COLOR REQUIREMENTS

- Alabama: Omaha Orange (Color 107, Army & Navy Specification, TTE 489, Class A)
- Arkansas: Omaha Orange (Sherwin Williams F10E 4141 Acrylic Enamel)
- Florida: DOT Yellow (DuPont Centari L9069A)
- Georgia: Highway Yellow (DuPont 174AH)
- Kentucky: White (DuPont LF-508, Lead Free Acrylic Enamel)
- Mississippi: Omaha Orange (Ford 5684, Chev. 88 or 982, paint number provided after bid award)
- North Carolina: Yellow (Moline, MPM 11-Y169A, Lead Free)
- South Carolina: Standard Yellow (DuPont 93-75306, Dump Body, Black)
- Tennessee: Orange (Chev. 88, Ford WT5684, International 0311, and GMC 88). Other brands, color specified after bid award. Body to match cab, DuPont 31AH Acrylic Enamel or Sherwin Williams F10E4143 Acrylic Enamel
- Virginia: Orange (DuPont LF74279AT, Lead Free)

- West Virginia: White (Federal Standard White 595A, No. 17875. Body, Martin Senour Dark Blue, No. 82-5802)

NEW JERSEY DEPARTMENT OF TRANSPORTATION (NJDOT) STUDY

- NJDOT has been requiring Lime Yellow (DuPont Centari, 7744A) since 1977 as the fleet color following the recommendation in a study by Dr. Stephen Solomon published in the early 1970s.

- Dr. Solomon presented scientific evidence that supported his theory that questioned the use of "fire engine red," which was then used on all fire fighting equipment. He recommended the usage of greenish-yellows that are more reflective in all lighting, weather, and perceptual conditions.

- NJDOT felt the color would be unique, and more readily recognizable.

- Human eye is most sensitive to color with 510 mμ (millimicron) wavelength (scotopic peak) in night lighting and that with 555 mμ wavelength in day lighting.

- Greenish-yellows fall somewhere in the mid of color spectrum where these scotopic (night) and photopic (day) curves cross over.

- Reflects 66.7% of light vs. 57% reflected by standard yellow color.

TEXAS DEPARTMENT OF TRANSPORTATION (TXDOT) STUDY

- With the advent of the tightened rules for application of leaded paint, by EPA and OSHA, and new use of clear coat paint systems by manufacturers in 1986, organic pigments used in the new paints no longer matched Federal Yellow, TxDOT's standard fleet color, beginning in 1986.
  - By 1987, orders for non-standard paints delayed delivery of both automotive products and heavy equipment by up to 8 additional weeks.
  - Based on annual purchases of automotive equipment, research in 1987 revealed a possible savings of $40,000 per year, if standard colors are ordered.
  - Studies by TxDOT Occupational Safety Division revealed that white has a higher light reflection percentage than yellow or orange.
  - TxDOT determined that acceptance of standard colors would shorten delivery time.
  - Based on researched data, coupled with TxDOT's commitment for responsible purchasing practices and emerging concerns for the environment, the decision was made to change TxDOT's fleet color to the manufacturer's standard white, in certain instances.

- Specific applications
  - Manufacturer's Standard White - All on-highway equipment, including vans, carryalls, station wagons, light, medium and heavy duty trucks, and trailers used to haul equipment.
  - Federal Yellow (No. 13538 of Federal Standard No. 595a) -All off-road equipment, such as construction equipment and trailer-mounted equipment towed behind vehicles (air compressors, arrow boards, etc.).
  - Manufacturer's Standard Pre-approved Light Colors - Sedans. Beginning in 1993, sedans also will be white.

- Candlepower of white compared to other colors
  - White is the brightest and most reflective color, with a light reflection percentage of 84.0, followed by Yellow at 57%.
  - The Lime Yellow used by the New Jersey Department of Transportation, has a light reflection percentage of 66.7.

- Advantages and Disadvantages determined by the TxDOT Study
  - In summary, the advantages of the use of standard paint colors are:
    - Cost ($40-$50 per unit on sedans, light duty pickups, etc).
    - Delivery (Earlier delivery ranging from 30 days to 8 weeks).
  - Disadvantages associated with use of non-standard or white paint:
    - Economically infeasible on heavy equipment (Manufacturers advised that non-standard paint, whether white or orange, adds approximately $500-$700 in cost to each unit ordered.)
    - Usage of white would mean having a two-color fleet for several years.

- Use of non-standard colors means less money at resale. This is based on data gathered by DuPont and Automotive Fleet Magazine, July 1991. Henry Ford's old axiom that you could buy it in any color you liked as long as it was black no longer holds true.
- Non-visibility of white in snow areas.

CURRENT TRENDS/ACTION

- Paint specifications and their standardization were recently discussed at the Southeastern States Meeting. Each attendee brought a paint chip representing their current specification. The results were most enlightening. Each time a paint chip was chosen by an attendee, it was similar to that person's state requirement, but the chip chosen was the wrong shade in most instance.
- Vendor information suggested a considerable savings if the states were more uniform in their color choices.
- States should consider accepting the manufacturer's standard shade of the desired colors.

BOTTOM LINE

- This issue is difficult to address, as there are strong feeling based on long-standing traditions. There is definite merit, in regard to economic benefits, safety, and environmental considerations, to reconsider current policies and practices regarding paint specification requirements for equipment. Texas undertook what some describe as a progressive move in 1988, and what others described as a more radical move, in requiring manufacturers standard colors for fleet vehicles. However, the benefits as described earlier have proven to outweigh the disadvantages. Alabama is currently considering an even more progressive move to extend this practice to their off-road equipment.

- We feel it is time for other states to consider these benefits as well. We encourage the state DOT's to begin discussing these issues and work through their regional meetings to determine the suitability of adopting manufacturers' standard colors, or the adoption of a nationally recognized standard color.

REPORT ON REGIONAL EQUIPMENT MANAGERS' CONFERENCES

Robert W. Kuenzli, *Consultant*

The State Highway Regional Equipment Managers' Conferences occur annually within their respective geographical areas. The meetings are one of many benefits that members enjoy. Valuable also is contact with members throughout the year by telephone, FAX, letters and occasionally in person. Others not involved in State Highway fleet activities could benefit by forming their own common interest groups. Examples are smaller groups within a geographical area involving other public sectors such as cities, counties, fire and transit districts and the private sector with fleets such as dump truck operators, food and hard goods, utilities and construction companies.

The State Highway Regional Equipment Managers' Groups are comprised usually of one principal management representative who has fleet management, fleet operation or related fleet managerial responsibilities. Often the representative is the principal manager of the State's fleet or the manager of fleet operation, fleet repair and shop operation or fleet specification, purchasing and fleet supply and parts operation. This mix of management responsibilities and expertise enhances the regional group makeup and is especially beneficial during the annual meetings. Each regional state is encouraged to have a representative at the meeting. If additional representatives attend, these guests are encouraged to minimize their involvement to allow for a structured and productive meeting. Often these guests are asked to comment and offer input but are not on the agenda. The reason for limiting input from guests is to allow complete coverage of the agenda items in the time allocated. Discussions before and after the formal meeting are beneficial and allow observers to comment and learn.

The meetings are of a hands-on nature sharing information and of a "workshop" makeup. The meetings have a structured, printed agenda with the principal purpose to share information, experience, concerns, problems, new concepts, regulations, equipment types and designs, and all aspects of fleet management, operations and involvement. Subjects may include personnel matters, shop management, purchasing, specifications, environmental concerns, parts and supplies, fleet operation and management. The meetings are intensive covering broad and involved areas of activities encompassing State Highway type equipment and operations.

Each regional group functions independently, however, their makeup, goals and objectives are very similar. The annual meetings usually are two to two and one-half days and are hosted by a different state each year usually on a rotational basis. The host state often encourages their middle managers and some staff members in their fleet and related operations to attend as observing guests. The host state for the next annual meeting is determined at the conclusion of the present meeting. The next year's host state has the responsibility to arrange and "chair" the meeting. This involves selecting the meeting site, room accommodations and other logistical items. Also, each state's representative is usually contacted three months prior to the meeting and invited to suggest or request agenda topics. The agenda format often differs between and within the regional meetings. Sometimes they allow each state an hour or more to discuss and gather input on specific subjects that they have requested. Another agenda format identifies "the subject" and the discussion unfolds with representatives participating. Mailing the agenda to members a few months prior to the meeting, along with meeting dates, location, accommodations and information allows members to make plans and reservations.

At the conclusion of each meeting or within a few weeks, the host state provides a list of names, addresses and telephone numbers of the states' representatives to each participant. Usually group photographs taken at the meeting are sent. A flow of information continues all year between participants and others involved in specialty areas from each state. Members value contacts throughout the year with member states and with representatives from other regions.

Most groups do not allow manufacturer or business representatives to attend the formal portion of the meetings. On occasion a manufacturer or product representative may be invited for a brief presentation. These presentations are usually generic in nature but may address specific concerns that members have voiced. No advertising is permitted in the meetings.

The first state highway equipment regional group was formed by the Equipment Managers from the states of Washington, California and Oregon. After numerous telephone conversations they met in a motel at the San Francisco Airport in 1969. Subsequently the Western States Highway Equipment Managers' Group has met annually. The last meeting was hosted by the Equipment Section of the Colorado Department of Highways at Glenwood Springs, Colorado in September 1991.

Over the years the Western Group encouraged the formation of other regional groups with guests from other states attending meetings for inspiration and input.

These included Nebraska, Oklahoma, Arkansas and Texas. Texas became a member of the Western Group in 1982. Later Nebraska, Arkansas and Oklahoma became members of their respective regional groups and were instrumental in their formation and development. As the "word and message" spread in the 1980's and with the support of the Transportation Research Board (TRB) Committee A3C08, *Maintenance Equipment*, then chaired by Bob Flaherty, other groups have been formed. The Southeastern Group was formed in November 1987. Later the Midwestern Group was formed in 1989. The TRB Committee A3C08, now chaired by Doug Nielsen, along with members of all three Regional Groups encourage and support the formation of a Northeastern State Highway Equipment Managers' Group. Members of the existing regional groups have made continued contacts over the years and continue to pursue formation of a Northeastern Group.

Many of the topics discussed at the various regional meetings are the same or similar. This similarity enforces the concept that most problems and information are common throughout the country. A few exceptions may be snow plow design in Florida or tropical vegetation and mowing equipment in Alaska. Some examples of subjects addressed at the last regional meetings and topics scheduled for the 1992 meetings along with meeting locations and dates are:

- The Southwestern Group of twelve states formed in 1987 held their last meeting April 21 through 23, 1992, hosted by Tennessee at Pigeon Forge. Their next meeting will be hosted by North Carolina probably in April 1993. Some subjects addressed at the last meeting included recycle update, water base traffic line paint, medium duty trucks, equipment disposal, equipment management update, preventive maintenance program, equipment management study, tire and oil filter disposal, Freon discussion, specification review, pavers, mowers and rollers, and responses and discussion of a question and answer survey mailed out prior to the meeting.

- The Midwestern Group of thirteen states formed in 1989 had their last meeting in June 1991, hosted by Kansas and held in Olathe just outside Kansas City. The next meeting will be hosted by Minnesota and held in Minneapolis in June 1992. This group has invited as guests Provincial equipment representatives from two neighboring Canadian Provinces. A representative from Manitoba has attended several times. Subjects covered at the last meeting included optimum replacement time for light trucks, truck hydraulic systems and spreader controls on dump trucks, comparison of snow plow specifications, equipment procurement procedures, alternate fuels, gasoline versus diesel in light duty trucks and pickups, tire management and underground fuel storage tanks. One of the highlights of the meeting was a tour of the equipment shop area and display of Kansas DOT equipment.

  Subjects to be discussed at the meeting in 1992 include mowing equipment, truck-mounted attenuators, disposal of oil filters and other hazardous material, melting applicators for rubberized asphalt, specification comparisons of loaders and backhoes, heated windshield on some vehicles and experiences with electric diesel engine controls.

- The Western Group of fourteen states formed in 1969 held their last meeting in late September 1991 hosted by Colorado at Glenwood Springs. The next meeting will be hosted by Montana and held at Helena on September 29, 30 and October 1, 1992. For various reasons Hawaii and Alaska are not always represented. The group has never met in Hawaii, but dreams of a 50th anniversary there! Subjects of the last meeting included fleet policies and procedures, mechanic training, shop management and supplies, truck-mounted attenuators, equipment purchasing and specifications, tires, disposal of equipment, equipment information systems, clean burning alternate fuels, multiple use equipment, pavement striping equipment, snow blowers, snow plow design and electric controlled diesel engines. Subjects for the 1992 meeting are now being collected and were not available.

- The proposed Northeastern Group, consisting of the states of New York, Pennsylvania, Maine, New Hampshire, Vermont, Connecticut, Massachusetts, Rhode Island, New Jersey, Maryland, Delaware and District of Columbia, has not become a reality. Many contacts have been made but never finalized. With continued interest and encouragement by the other Regional members, TRB Committee A3C08 and the involvement of Ed Fahrenkopf of New York and others in the Northeastern area, this group may become reality.

  Mr. Fahrenkopf, also a member of the TRB Committee A3C08, in an effort to initiate interest that may spark the formation of a Northeastern Group has been successful in having equipment issues included on the agenda for the regional

Highway and Transportation Maintenance Officials' meeting of New England, New York and New Jersey. This meeting was held in September 1991 and included 39 participants from Rhode Island, Maine, Vermont, Connecticut, New Hampshire, New Jersey and New York State Thruway Authority. The equipment items discussed at this meeting were CDL training, thermoplastic versus water borne paint and the associated application equipment, truck-mounted attenuators, truck and plow lease or rental equipment financing, prototype dual direction dumping bodies and reduction moving operations. Mr. Fahrenkopf indicates that the equipment related discussions at this meeting were productive; however, he will continue to pursue the formation of a regional meeting dedicated solely to state highway equipment matters.

The value of these regional meetings results from the strengths of their participating members sharing for the common good and the benefit of the system.

SECTION II EQUIPMENT RESEARCH

SHRP'S EQUIPMENT RESEARCH FOR MAINTENANCE COST-EFFECTIVENESS

Shashikant C. Shah, P.E., *Strategic Highway Research Program*

MAINTENANCE COST-EFFECTIVENESS

The major objective of the Strategic Highway Research Program (SHRP) research in the maintenance cost-effectiveness (MCE) area is to make technological improvements in equipment, materials and processes by increasing pavement service life, productivity and worker/motorist safety. This will improve the capabilities of the states for developing budgets, administering programs and allocating resources.

Figure 1 lays out the 10 contracts that constitute the MCE portion of the Highway Operations research program. The figure shows the interrelationships of the contracts. The solid lines denote the progression toward follow-on contracts. The dashed lines indicate the need for coordinated effort between separate contracts. The equipment development contracts are identified as H-104 and H-107. Both these contracts are geared towards development of new equipment for:

Pavement Condition Evaluation

Two separate equipment units are under development under H-104, one at the network level and the other at the project level. These automated equipment units will make it easier for maintenance technicians to keep track of the condition of a road network. The equipment units will assist in both the network-level and project-level decision-making about preventive maintenance.

Pavement Repair

A crack filling robot and an automated pothole repair machine are under development under the category of pavement surface repair equipment, contract H-107. Both equipment units, when operational, will reduce labor costs, provide quality repair and reduce the exposure of maintenance workers to risks.

MAINTENANCE MEASURING EQUIPMENT - NETWORK-LEVEL

The network-level equipment units for pavement condition evaluation uses ground penetrating radar (GPR) to collect data quickly on subsurface conditions that can lead to pavement distress. This includes potential distress caused by moisture in asphalt subbase, voids or loss of support under concrete slabs, and overlay delamination. Figure 2 is a sketch of the equipment unit.

The trailer mounted radar equipment can be operated at speeds of up to 25 mph (40 kilometers per hour). The data acquisition and interpretation is rapid and accurate due to the high resolution radar system and enhanced data interpretation software.

MAINTENANCE MEASURING EQUIPMENT - PROJECT-LEVEL

The project level equipment for early detection of subsurface conditions uses seismic wave analysis techniques to measure localized pavement conditions. This trailer-mounted (Figure 3), low-cost equipment is designed for maintenance technicians to measure moisture in foundation layers of flexible pavements and under rigid pavement joints, fine cracking, voids under rigid pavement joints, and overlay delamination. With this equipment, early symptoms of pavement distress can be identified, measured and diagnosed to take timely action to prolong pavement life.

Innovative Equipment for Surface Repairs - Crack Filling Robot

A robotic crack filling machine is being developed to seal/fill pavement cracks in less time than what is done manually at the present. The robotic truck is highly automated and will require only two operators to accomplish the job that currently requires from six to eight workers.

The equipment unit will fill and seal both longitudinal and transverse cracks using vision sensors and mechanical robots (see Figure 4). When operational, the automated vehicle will repair cracks faster and more consistently than do typical repair crews. One of the major benefits will be increase in worker safety because all operations will be from inside the vehicle.

Innovative Equipment for Surface Repairs - Pothole Patcher

Another equipment unit being developed is a one person operated pothole patching machine that will perform all patching operations that normally require from four to

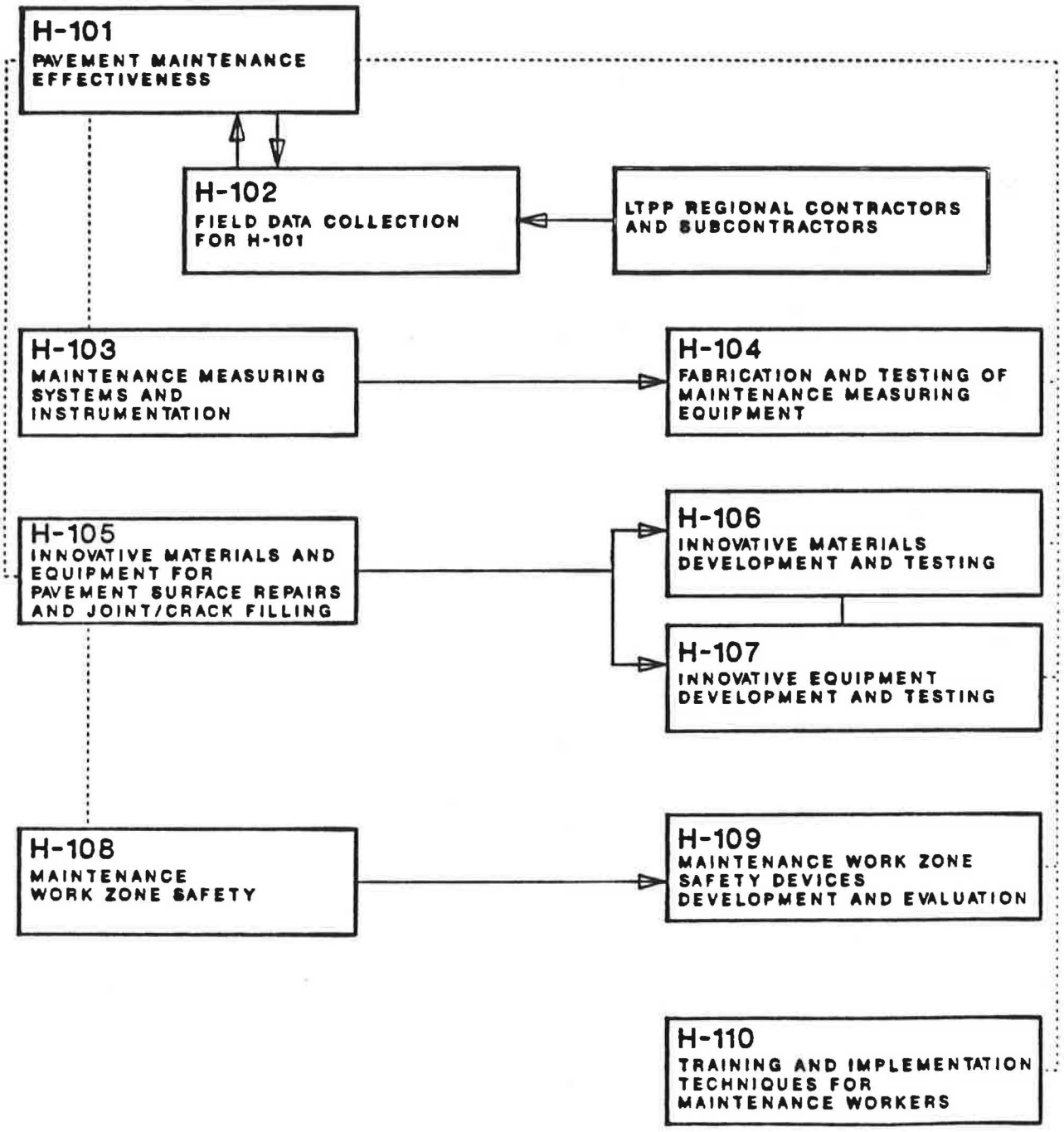


Figure 1 Contracting Plan for SHRP Maintenance Cost-Effectiveness.

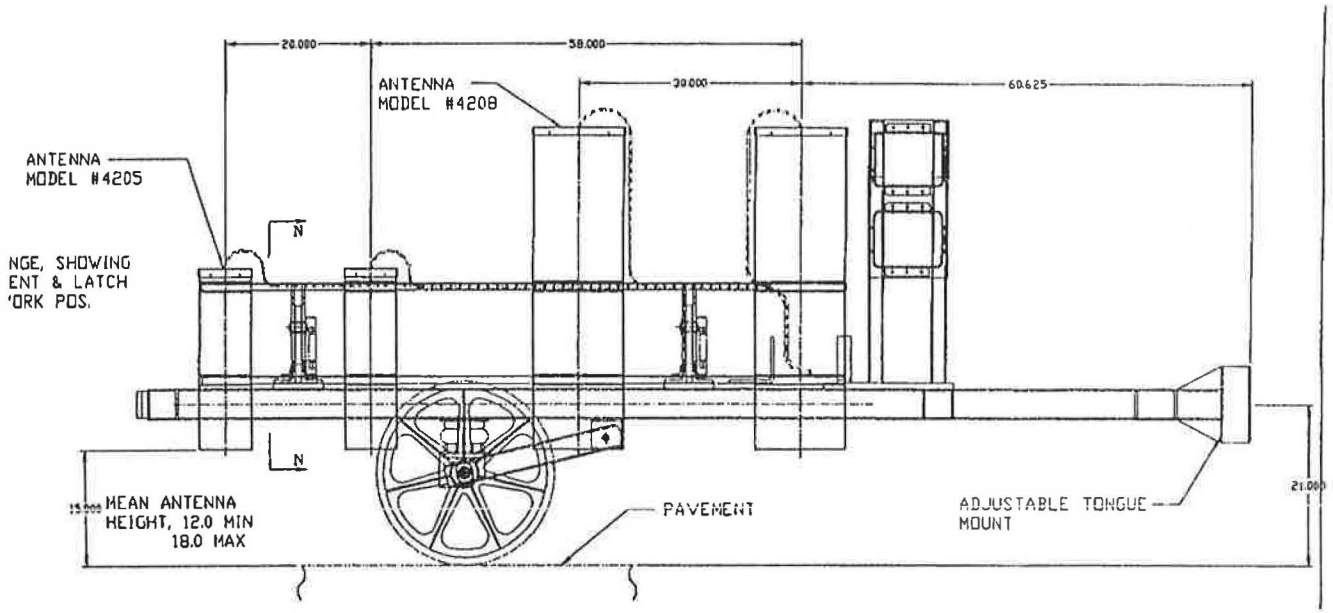


Figure 2 Network Level Maintenance Measurement Equipment (Subsurface Interface Radar).

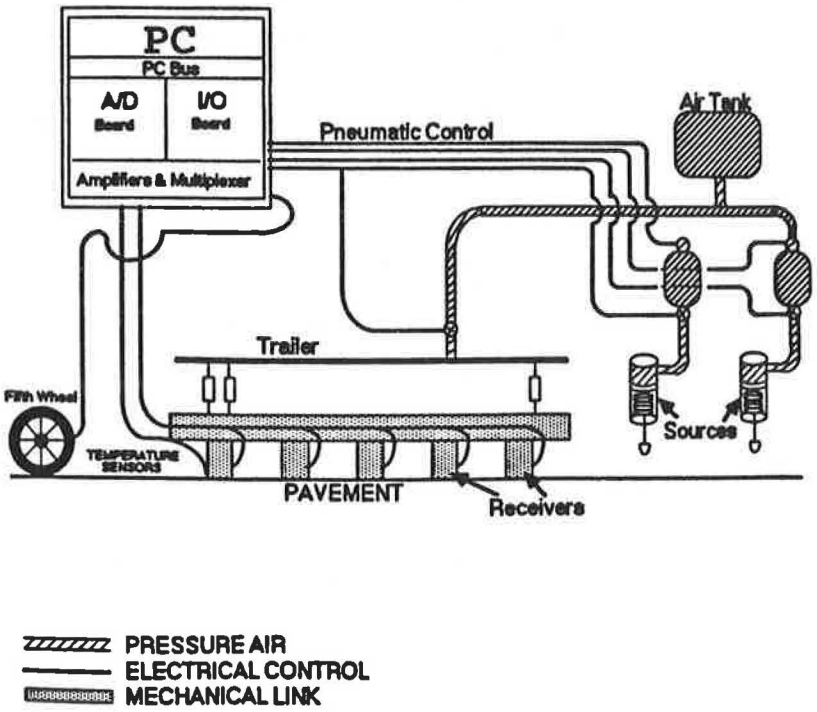


Figure 3 Project Level Maintenance Measurement Equipment (Seismic Surface Analyzer).

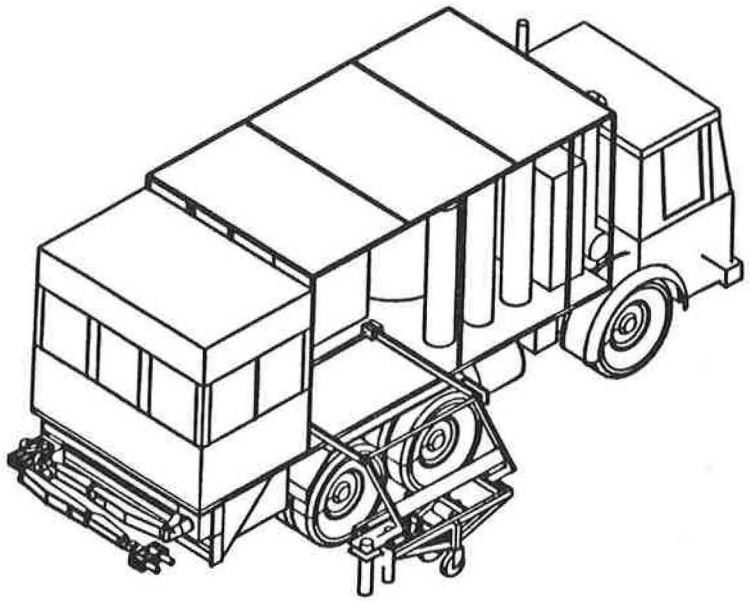


Figure 4 Integrated Crack Sealing Machine.

six workers. This robotic machine will cut the edges of the pothole, vacuum up the loose materials, dry and heat the hole surface and fill the hole with material at high enough velocity that it does not require additional compaction.

The truck is designed to accommodate two aggregate hoppers, asphalt emulsion tanks and all other mechanical and hydraulic systems. The repair system is housed in the repair box at the end of the truck. Within the repair box, a stereo-vision system will determine the outline and depth contour of the pothole. This will assist the operator to spray the exact quantity of patch material into the cavity. The automated equipment will not only increase the quality, consistency and life of the patch but also will increase the safety of workers. Figure 5 is the sketch of the prototype pothole patcher.

CURRENT STATUS

All of the above equipment will be available for demonstration sometime in 1993. The prototype equipment may require extensive testing and evaluation. It is expected to lead to commercially available units sometime in 1995.

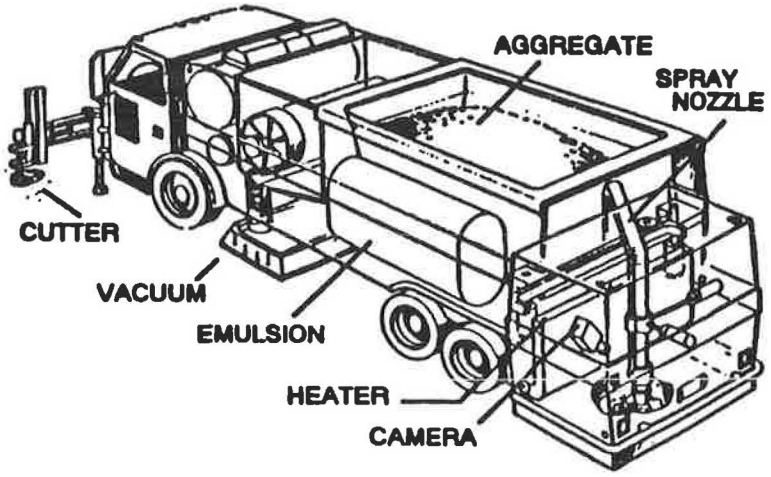


Figure 5 Cutaway View of the Pothole Patcher.

AUTOMATED POTHOLE PATCHER

James R. Blaha, *Basic Industry Research Laboratory (BIRL) at Northwestern University*

INTRODUCTION

Most state highway agencies use a labor intensive procedure for the repair of potholes in asphalt pavements. This creates several problems that are increasingly difficult to tolerate. For example, safety factors, frequent repair, and high maintenance cost are some of the concerns of the state highway agencies and the public.

Worker and traffic safety are difficult to maintain on our nation's highways, particularly during the repair seasons of winter and spring. The statistics of work zone related casualties indicate the importance that must be placed on research addressing safety issues. SHRP H-107B program takes the approach of improving safety for all concerned by automating the pothole repair process, removing workers from the road, and speeding up operations to reduce the traffic hazard.

Many equipment manufacturers and material producers are claiming to have developed products to reduce the need for intensive preparation of the pothole cavity and surrounding area. Some proprietary cold mix materials have demonstrated good performance in wet conditions with little post-compaction. Their widespread use has been hampered, however, by high material costs and a reluctance on the part of agencies to allow the "throw and go" technique.

Automation can make it cost effective to prepare a pothole using today's materials. A permanent pothole repair procedure used by many agencies involves cutting pavement, cleaning out debris, tack coating, filling, compacting, and sealing. Specialized equipment and trained laborers are required to effectively accomplish these tasks. However, this "do-it-right" repair procedure is labor intensive and with low cost hot-mix, the final cost of a pothole repair can exceed $100. These funds can be wasted when a lack of skilled workers or poor weather conditions can make it difficult to "do-it-right." This program is developing equipment that will demonstrate the economic potential of automating the pothole repair process. Rather than reinvent the shovel, the development strategy has been to use existing repair technology, and then computer-automating, selected components into a vehicle that will automate the pothole repair process. In one sense, automating the pothole patching process can be compared to a manufacturing process where raw materials, tools, and a process plan all combine to produce a product--the roadway patch. The missing link until now has been the creation of a pothole-patch process control system on wheels.

BIRL, the applied research laboratory of Northwestern University, has designed, fabricated, and will soon begin a field testing of a complete vehicle system for the repair of potholes in asphalt pavements.

OVERALL PRODUCT DESCRIPTION

Potholes come in all sizes and shapes. Defining them is difficult and little guidance is found in the literature. For this program, we use a pragmatic definition, "a pothole is in the eyes of the beholder," in this case the operator of the pothole repair truck. We would like the operator of our truck to be able to fix anything he or she considers to be a pothole. Potholes may have a base of asphalt, sand, rock, concrete, cobblestone, or whatever. They may be water-filled, mud-filled, or contain foreign objects like a muffler part or in some cities an occasional Volkswagen.

Usually, they are bowl-shaped, from 1 to 10 square feet in area, with a depth of 2 to 6 inches. They most often occur in the wheel paths of traffic or at the centerline or along edges where overlays have met. Surface water, drainage, and traffic loading are primary factors in the creation and growth of a pothole. The pothole may lie adjacent to concrete, thus making it difficult for pothole routing and shaping tools. They also may lie in areas that collect water, such as a depressed area at a bus stop or near a curb. Potholes may be closely spaced or they may lie at random intervals along a road. Each of these variations present different problems to the computer automation of the repair process. During this two year-long program, we have developed a system capable of handling most of these variations (except the Volkswagen).

At the start of this program in December 1990, SHRP provided a set of requirements and guidelines that we have implemented in our design. It was felt that the best solution would be a single vehicle capable of moving about on the highways under its own power with enough materials and capacity to handle a whole day of patching. It was desirable to make repairs over an entire lane width, with minimal shutdown of the adjacent lanes. It had to operate rapidly to realize economic goals and to make the system safer for the traveling public. The less time spent stopped for repair, the better. A minimum of crew was also desirable to improve safety. The state highway agencies were targeted as the end users, so operating and capital costs were to be kept as low as possible. We set a goal of

$250,000 for the first prototype equipment cost and we have met that. Breakdowns and equipment maintenance requirements were to be kept to a minimum. We recognize that a machine of this size, if kept in the shop for repair, is worse than useless. Wherever possible, our designers have sought simple and no-maintenance approaches for each component. The system had to be designed to address the application of different patch materials, not just a single selection finely tuned to the capabilities of the truck. Finally, it had to be highly automated to assure consistent patch quality with nearly permanent lifetimes, at minimal in-place costs. Permanent patches were considered to last the remaining life of the surrounding road, anticipated to be 3 to 5 years.

PRODUCT FEATURES AND DESIGN

We call the system the Automated Pavement Repair Vehicle (APRV). The vehicle is based on a truck chassis by Crane Carrier Company (CCC). The "Low Entry Tilt" (Model LET) is often used in the refuse industry where gross vehicle weights can run high, and turning radius is critical. The CCC has the best turning angle of the 4 trucks we examined. The truck has a turning radius of 22.7 feet for excellent maneuverability to reach potholes and pavement distresses wherever they are found.

The frame is structural steel ship channel of high modulus, heat treated and then straightened to eliminate racking and twisting problems. The 10 inch rails extend from the front bumper to the tailboard. Heavy duty electrical systems and air brake systems are specified for this application.

The CCC model features a prime mover of Cummins Diesel L10 260 horsepower with a front-mounted power-take-off (PTO) that drives the hydraulic system for pavement cutting. An Allison automatic transmission equipped with an eight-bolt PTO powers the blower. Slight adjustment of the engine speed from normal idle of 700 RPM to 1100 or 1500 RPM is all that was required to drive the blower and hydraulics efficiently.

An additional generator provides 12 kilowatts of electrical power for the computer systems, lighting, vision systems, and sensors. The vehicle chassis will handle a gross weight of 62,000 pounds, though we expect to operate at less than that with a full load. With a wheel base of 200 inches, body width of 8 feet, and height of 10 feet, the overall size has been designed to make it legal in every state.

Although the driver is the only required operator, we provided a crew cab for additional crew or observers on day-long repair excursions. The crew cab gives air-cushion ride for 3 or 4, in air conditioned comfort. We will mount the computers and displays in the crew cab in a shock-mounted cabinet for extra protection. Hard disk drives for the computer systems may be eliminated in favor of optical disk drives. The entire software for the computers could be contained on a single three and one-half inch, replaceable optical disk, thus making software upgrade a simple process. Keyboards are out, and mice are impractical, so a touch screen is the best interface for an operator. We are designing the system for use by a skilled individual, such as a gradeall operator--not a rocket scientist. A training program would not require more familiarity with computers than the local "Lotto," video game, or automated teller machines.

A physical model was constructed to 1/8 scale to resolve issues in component placement and overall body design. We felt this approach was an inexpensive alternative to computer modelling, since we could carry the model to vendors for their viewing when they made quotations for equipment. Some portions of the truck were made full-scale so the operator interface could be developed without having the truck chassis on hand. Everything has been laid out to make the system easy to maintain and productive in use. From the outset the design team has tried to eliminate knee-knockers and maintenance problems.

Each of the subsystems has been designed with 6 driving factors in mind. **Repair performance** includes patch lifetime and annualized cost per repair. The objective is a patch lasting 3 to 5 years and costing less than a permanent pothole repair by traditional means. **Low maintenance** is essential for commercial viability and highway acceptance. Field breakdowns must be minimal. Simple maintenance should be accomplished without disassembly. Part wear must be controlled and minimized. Automated self-cleaning is desirable. **Safety** to the crew and public is emphasized. Since most industrial accidents happen during equipment maintenance, lowering maintenance frequency actually improves safety. Safety interlocks prevent crew from exposing themselves to risks of operation. Since the single crew member never leaves the cab, there is great potential to reduce traffic related injuries when using this system. The APRV must be **easy to use**, particularly on cold and rainy days. The emphasis must be to make it easy to use and let the operator feel confident that he is controlling the system to help him do pavement repair. Autonomy must be balanced with suitable manual overrides. Controls must be intuitive and not require a light touch or a steady hand that will strain the nerves of the operator over the course of the day. **Cost of operation**

and maintenance must be low. Production model pricing also should reflect state budget restrictions, thus options to lease must be available. The sixth driving factor in the design is **versatility.** The design should accommodate all sizes and shapes of potholes and other pavement distresses that broadly fall into the definition. If the operator thinks he can repair it, he will find a way to try. The machine must allow for this without breaking down. Also, a strong plus is given to a system that can be used for multiple purposes besides pothole repair, such as crack sealing, utility cut patching, or shoulder reconstruction.

With respect to these design priorities, let us review the conceptual drawings. Gull-wing doors over the dual 13 foot aggregate hoppers permit a 12 foot wide loader to dump a bucket directly into each of the 4 cubic yard hoppers with minimal spillage. The covers will keep the weather off the aggregate during storage and improve the aerodynamics and safety of the system in transport. Heavy-duty edges prevent accidental damage from the loader. The dual emulsion tanks each have a capacity of 180 gallons. They are heated electrically (120 volts) and they may be kept warm with engine heat during operation. Ideal emulsion temperature should be between 120 to 160 degrees Fahrenheit. Heat prevents clogging and improves the flow of the emulsion. Side panels can be removed for easy cleaning. The tanks are not pressurized and seals are not a problem.

Many states have specified pothole repair procedures. Some agencies and institutes have studied these procedures over the years and made recommendations. The state's repair procedures vary, as well as the equipment and materials used to perform them. Thus, we had to determine a generic procedure that seemed to satisfy all the state's requirements and that could be flexibly utilized by individual states. The APRV will perform 2 generic procedures using equipment specially-developed for this program or adapted from commercial products.

The repair sequence could be performed as follows.

Step 1: The driver could locate a hole to be repaired using his eyes and a downward-pointing CCD camera looking through the windshield. With a cab-over-engine design on the truck, the operator will be able to see a point on the road 2 feet in front of the plane of the windshield. He will then point to the target hole on the touch screen of the display. A bumper-mounted lightbar can be used at night to sight the potholes.

Step 2: The driver could use joystick control to manipulate the bumper-mounted pavement cutter to clean and shape the edges of a pothole. Some states do not perform pothole cutting with some materials so this is an optional step.

The hydraulically-operated cutter uses a vertical-milling principle. The cutter head contains several carbide-tipped bits that can be easily replaced in the field. It is rotated at high speed to achieve the shear forces needed to cut asphalt pavement. Although maneuvered by joystick located in the cab in the prototype, it could be fully computer-automated. It can shape the edges of a 4 square foot pothole in a few minutes.

Step 3: The truck could then be driven forward about 25 feet in a creep-gear until the pothole is positioned under the repair box area at the rear of the truck. Exact alignment is not required and the computer vision system can provide assistance.

The rear of the truck has an overhanging area we call the repair box where most of the repair takes place. The repair box houses the repair equipment. Doors on the underside of the box unfold to pavement level to keep weather conditions away from the repair as it is made. They also confine the repair process and materials to the repair area. Thus, we can bring a warm summer day to the pothole, day or night, rain or shine. The payback analysis we have done shows the impact of keeping a machine operating two or three shifts, for 300 or more days of the year.

Step 4: A 3-dimensional vision system located inside the repair box could scan the 5 x 8 foot pavement area under the box to detect the depressed area of the pothole as well as cracks. Styrofoam models of potholes were created to test these concepts in the laboratory. Scanning the pothole by laser light allows it to be seen in detail, even in changing lighting conditions. This system will show the operator a 3-dimensional graphic display of the pothole surface, including accurate readings of the depths and overall dimensions. It also will send this data to a robot to perform the rest of the repair sequence.

Step 5: The robotic arm could extend from its retracted position to move a vacuum nozzle down into the cavity. High power vacuum sucks out water, mud, and cutter debris. Enough power should be available to suck up large asphalt chunks. The vacuum system has stages of filtration that empty into a waste hopper that is dumped from the passenger side once per day. The filtration should be economical yet very efficient to protect the blower intake from receiving damaging dust and water from the pothole vacuuming process. Maintenance of

this component should be infrequent and involve simple and inexpensive filter replacement.

Step 6: The same robotic arm then could ignite and move a hot air lance across the pothole surface, to heat the surface and bonding edges of the cavity. The hot air lance is commonly used in highway applications for crack filling, because an intense blast of heated air is ideal for heating and drying pavement surfaces. The lance is a handheld torch powered by liquid propane gas and compressed air. We have constructed a safe electrical ignition and gas control system to operate the lance automatically. The system has no open flame, yet very high exit temperatures can be achieved. The temperature of the pavement will be closely monitored to assure that no overheating takes place. In our tests with the lance, we have brought 50 degree pavement up to 150 degrees with about 10 seconds of heat over a small pothole area. Larger areas will require back and forth movement of the lance to distribute the heat evenly. The truck usage of propane is estimated to be less than two RV-sized propane cylinders per week. Storage for four cylinders is provided.

Step 7: The next step would be the application of patch material. We feel that spray emulsion or spray injection has the best promise for complete automation and the creation of a consistent and permanent patch at minimal cost. The patch material cost is about $22 per ton. We have developed a spray patching system that matches our design goals and in our trials it has exceeded the performance of commercially available systems. The spray patch concept conveys rock aggregate in the size range of 1/4 to 1/2 inch into a high speed air stream. The rock moves down a tube or hose to a point within one or two feet of the pothole. Just before it exits a nozzle, it is sprayed with asphalt emulsion, thus making the patch material on the fly. As it strikes the cavity, the emulsion breaks, the patch begins to cure, and air voids are removed as the patch is built from the bottom up. Experiments with our spray patcher have demonstrated it shooting rock out of the nozzle at a speed of nearly 100 mph. The overall material discharge rate is about one cubic foot per minute and it is controllable. This will allow the automated filling of a thoroughly prepared pothole cavity with commonly available patch material.

Step 8: After the computer has controlled the filling of the pothole cavity, the robotic arm could vacuum away any over spray from the patching process, thus leaving the repair site clean. The doors of the work box will close and a green light will signal the driver to drive to the next pothole. Enough material and waste storage is on-board to allow all day operation without stopping. Liquid propane gas is easily refilled on a weekly or bi-monthly schedule depending on the season and the climate.

CONCLUSION

Referring to the original design goals, we are constructing and testing a vehicle for pothole repair in asphalt roads. It should have a repair cycle time of 5 to 10 minutes, yet require only a single driver/operator. It will function across a full lane width, up to 8 feet by 5 feet at a time, performing a generic permanent pothole repair procedure. We hope that a commercial system will be low maintenance and easy to use, costing in the area of $300,000 in limited production and lower-priced versions sure to follow in the marketplace. Based on all considered costs, we target the in-place patch cost to be less than $30 for a two square foot hole. It will be automated to improve safe, rapid repairs in day or night, most weather conditions, at most any repair site.

We anticipate the vehicle to be ready for field testing in the fall of 1992. States that can provide repair sites and materials are urged to contact us for more information. We are actively seeking commercializers for the truck and hope to see a production model available for purchase in 1993. Further information on this project is available by contacting me at BIRL, Northwestern University, 1801 Maple Avenue, Evanston, IL 60201-3135.

PAVEMENT CRACK AND JOINT SEALING AUTOMATED MACHINE

Steven A. Velinsky, *University of California, Davis*

ABSTRACT

The sealing and filling of cracks in highway pavement are maintenance activities that are routinely performed throughout the world to extend the time between major rehabilitations. These activities are extremely labor intensive, tedious, dangerous, slow, and costly. Accordingly, the Strategic Highway Research Program (SHRP) has supported the H-107A project to develop machinery to perform these tasks in an automated manner. This two and one-half year project is approximately half over, and this paper reports on the progress to date. This includes discussions of the development plan, the overall machine architecture that includes seven primary subsystems, how the machine will address pavement cracks, and design aspects and status of the seven subsystems.

INTRODUCTION

Worldwide, a tremendous amount of resources are expended annually maintaining highway pavement. In California alone, the state Department of Transportation (Caltrans) spends about $100 million per year maintaining approximately 33,000 lane-miles of flexible pavement (Asphalt Concrete - AC) and 13,000 lane-miles of rigid pavement (Portland Cement Concrete - PCC). A portion of these maintenance activities involve the sealing and filling of cracks (approximately $10 million per year). The purpose of crack sealing and filling is to prevent the intrusion of water and incompressibles into the crack, while crack filling is additionally used to hold broken pieces of pavement together. When properly performed, these operations can help retain the structural integrity of the roadway and considerably extend the time between major rehabilitations.

The sealing and filling of cracks are tedious, labor-intensive functions. In California, a typical operation to seal transverse cracks in AC pavement involves a crew of eight individuals that can seal between one and two lane miles per day. The associated costs are approximately $1800 per mile with 66% attributed to labor, 22% to equipment and 12% to materials. Furthermore, the procedure is not standardized and there is a large distribution in the quality of the resultant seal. In addition, while crack sealing/filling, the work team is exposed to danger from moving traffic in adjacent lanes.

The crack sealing/filling operation is an ideal candidate for the infusion of advanced technologies to automate the process. Automated crack sealing/filling machinery has the potential to:

- Minimize the exposure of workers to the dangers associated with working on a major highway.
- Increase the speed of the operation.
- Improve the quality and consistency of the resultant seal.

Increasing the speed of the operation will in turn reduce the accompanying traffic congestion since lane closure times will decrease. The combination of the increased speed and the higher quality seal will prove to be extremely cost effective and reduce the frequency of major highway rehabilitations. To have the greatest impact, such machinery should satisfactorily perform the following functions automatically:

- Sense the occurrence and location of cracks in pavement.
- Adequately prepare the pavement surface.
- Prepare and dispense the sealant/filler.
- Form the sealer/filler into the desired configuration.
- Finish the sealer/filler.

Additionally, the machinery will have many other more detailed overall functional specifications related to safety, cost, reliability, etc.

This paper discusses progress of the SHRP's H-107A Project, "Fabrication and Testing of Maintenance Equipment Used for Pavement Surface Repairs - Crack Sealing/Filling." The participants of this project include: University of California-Davis (prime contractor), California Department of Transportation, Bechtel Corporation, ERES Consultants, Inc., and Odetics.

MACHINE DEVELOPMENT PLAN

The development plan for the automated crack sealing machinery involves several critical aspects. The machine is divided into two main machine subsystems, one to address longitudinal cracks operating off the side of the vehicle, and the other to address general cracking, such as transverse cracks, off the rear of the vehicle. Each of these machine primary subsystems use identical components minimizing the parts inventory of the machinery. Also, each of the component subsystems is able to operate as a stand alone unit, which provides for the maximum flexibility in machinery configuration and allows for each user to outfit his machine according to

his personal crack sealing method. This will provide for the largest possible market. Figure 1 is a computer graphics rendition of the machine concept and this figure clearly shows the two main machine subsystems. Graphics animation of the concept vehicle has been an important tool in the development process.

To expedite machine development, component feasibility testing has been incorporated with first generation component testing whenever possible leading to the rapid development of application specific second generation components. Finally, the use of commercially available components whenever possible has been emphasized to maximize reliability and accelerate development.

MACHINE ARCHITECTURE

The overall machinery system architecture includes seven primary systems, Vision Sensing System (VSS), Local Sensing System (LSS), Applicator and Peripherals System (APS), Robot Positioning System (RPS), Vehicle Orientation and Control System (VOC), Path Planning Module, and Integration and Control Unit (ICU). Of course, these systems would in turn be mounted or towed by a support vehicle. The Vision Sensing System will be primarily responsible for locating and describing roadway cracks and joints. The Local Sensing System is a laser range finding based system to verify the presence of cracks and to provide fine position information. The Applicator Assembly and Peripherals include the hardware necessary to mix, heat, dispense, shape and finish sealant/filler, and to prepare the pavement including reservoir creation. This system may be comprised of any number of dispensers, valves, cutting tools, heaters, air compressors, etc. The Robot Positioning System will include the hardware necessary to move the applicator assembly end effectors in such a manner that they follow the required path. The required path is determined by the Path Planning Module based on the information provided by the VSS and the LSS. Physically, the Path Planning Module is software housed within the ICU. The Vehicle Orientation and Control System monitors and controls the vehicle position and speed, and it is necessary since the VSS is housed at the front of the vehicle and the RPS and APS operate at the rear of the vehicle. Furthermore, the entire crack sealing operation will ultimately be performed as the machine moves continuously down the road. The Integration and

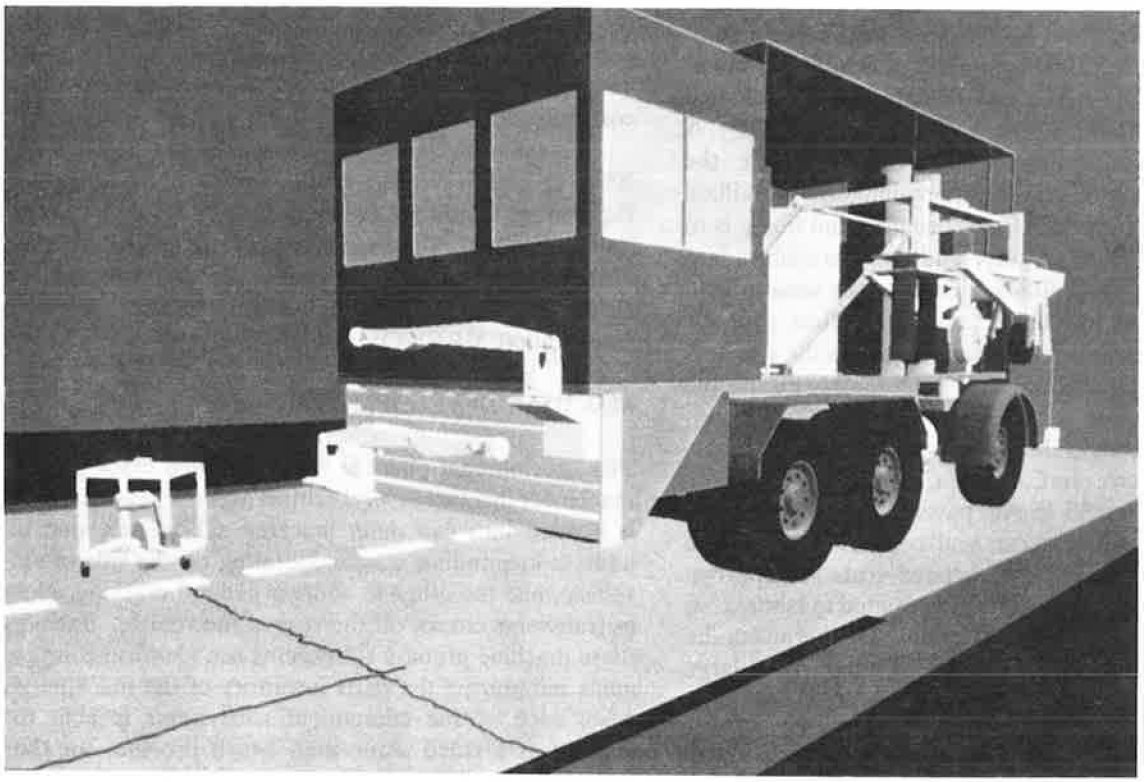


Figure 1 Computer generated pavement crack and joint sealing machine.

Control Unit will coordinate the Crack Sensing, Applicator Assembly and Peripherals, Vehicle Orientation and Control, and Positioning Systems. After the Path Planning Module transforms the information from the Sensing System into a desired path for the applicator assembly, the ICU will then control the motion of the applicator through the Positioning System as well as controlling the individual functions of the Applicator System. Additionally, the ICU will monitor all of the peripherals to ensure proper sealant/filler supply, sealant/filler temperature, heat supply, etc. Figure 2 shows the functional architecture of the machine in terms of computational integration. A brief description and development progress of each of these component systems follows.

Integration and Control Unit

The development of an Automated Crack Sealing machine (ACSM) includes the integration of a variety of sensing, command and actuating systems, many of which will synchronously perform tasks in real-time. A control architecture has been developed to assure that these systems act in a coordinated manner to achieve the overall goal of sealing pavement cracks at an acceptable performance level. The choice of the control architecture for a particular product can have a profound effect on the development as well as the commercialization of that product.

The Integration and Control Unit oversees the entire operation and coordinates the activities of the other subsystems. The information forwarded from the Crack Sensing System will be translated into a planned path for the Applicator and Peripherals System components (crack/joint preparation equipment, etc.). Thus, the Integration and Control System will include the necessary algorithms to plan a crack/joint sealing path. This path corresponds to the relative positioning of the Applicator System. If multiple applicators are employed, the Integration and Control System will need first to allocate cracks to the individual applicators and will do so in a manner to maximize speed and avoid interference. This system will keep account of the actual position of the total machine and its components by interacting with sensors on the Positioning System. It will additionally monitor the Applicator Assembly and Peripherals to ensure adequate volume and temperature of sealant/filler, air, etc. Following the planning of the

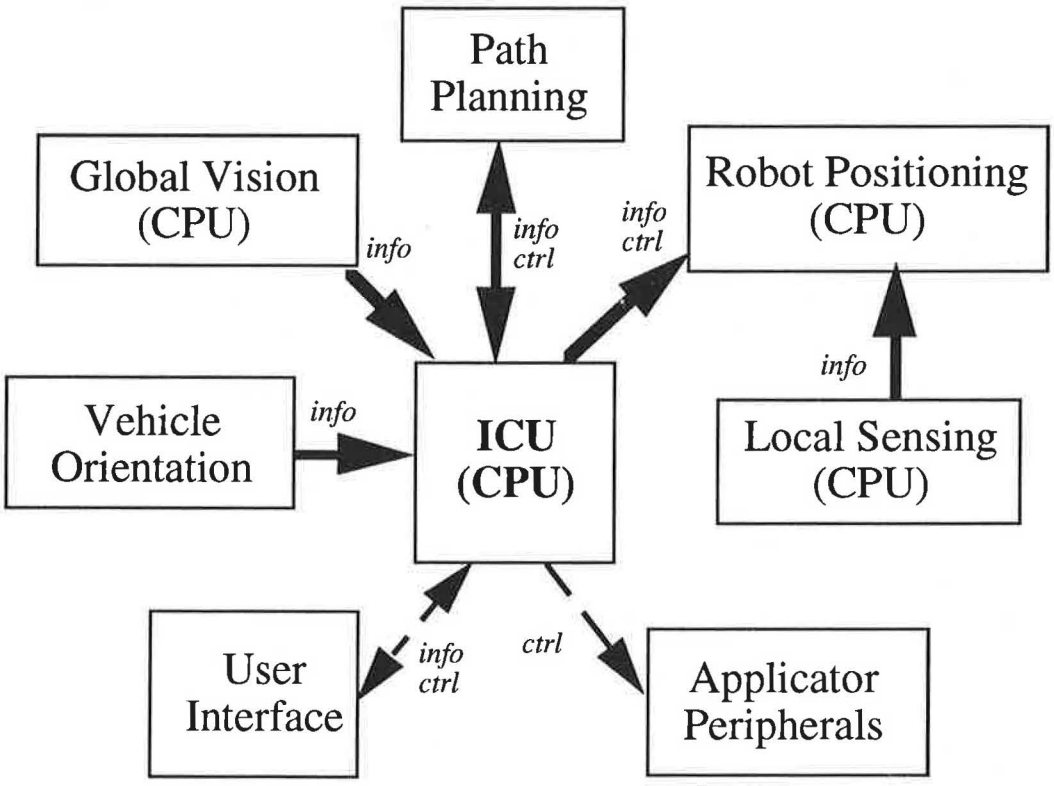


Figure 2 Machine Functional Architecture.

appropriate path(s), the Integration and Control System will control the motion of the applicator(s) and the individual applicator functions.

In review of the machine requirements, the ICU must meet the following criteria:

- fast and efficient computation,
- able to recognize and process prioritized interrupts
- process concurrent information rapidly (multi-tasking),
- retain sufficient spare capacity and flexibility to expand,
- support multiple processors, and
- expandable backplane.

In addition to these necessary requirements, other development requirements were recommended as follows:

- modular in both hardware and software design
- application software should be developed in a user-friendly environment that is common to many programmers,
- system software should be ROMable to enable an embedded application,
- vehicle mounted ICU needs to be rugged to operate in a hostile environment, and
- compatible with other CalTrans/UCD in-house development efforts and expertise.

Considering the responsibilities of task monitoring as well as the development requirements, a VME system bus architecture utilizing an OS-9 real-time operating system was selected as the most desirable based on all considerations and requirements. The VME bus provides the highest bus transfer rate, is rugged enough to perform in the maintenance vehicle environment and is a flexible system. The VME bus provides the flexibility, compatibility, modularity and multi-processing necessary for the efficient operation of the ACSM. OS-9 was recommended as the operating system for the VME bus because it is increasingly accepted as a standard and complies with the requirement to be compatible with other ACSM subsystems and other CalTrans and UC-Davis automated highway maintenance projects.

The VME computer system utilized is a commercially available system. Thus far, the basic control architecture has been implemented on this system. Communications have been established to several other subsystems and these have been demonstrated in real time. The preliminary user (operator) interface has also been implemented. That is, operator communication with the ACSM will take place through a computer terminal and the display screens have been designed and demonstrated providing a view of the types of information that will be passed on to the operator.

Vision Sensing System

The purpose of the Vision Sensing System (VSS) is to locate pavement crack positions using machine vision. The VSS processes information from a gray scale image of the top view of a section of pavement, approximately 12 feet wide (one lane width). Acquisition of the image is coordinated with the rotation of the ACSM wheels to maintain a proper aspect ratio of the pavement image. Hence, the image is created by the forward movement of the vehicle. As the computer acquires sufficient blocks of image data, a 10 inch long by 12 foot wide block of video data is built in increments of two inch square tiles. For each of the tiles the determination is made whether a crack exists, and if so, in which of eight directions is it headed. This data is immediately transferred to a remote storage area for path planning and updating from the ICU and Vehicle Orientation and Control System (VOC) as the vehicle continues to move forward.

The VSS has been constructed and preliminary testing has taken place with the use of the Odetics Mobile Imaging Laboratory. This laboratory is a truck with enclosed bed that contains adequate power, air conditioning, monitors, tape recorders, and other electronic equipment and mountings for vision system testing, and in particular, it contains Datacube vision processing equipment and support computers compatible with our vision system hardware. The VSS consists of two cameras, lighting, an encoder, and system unit that encompasses image processing hardware and crack detection algorithms. The lighting system has been designed to ensure operation both during the daylight and nighttime hours thus providing maximum usage of the ACSM. The preliminary testing has shown the ability of the VSS to locate cracks in both AC and PCC pavements as small as 0.2 inches.

Vehicle Orientation and Control System

The Vehicle Orientation and Control (VOC) system tracks the position of cracks on the road surface with respect to a fixed point (e.g. the robot base) located on the truck. This system is required so the position of road cracks identified by the Vision Sensing System (VSS) at the front of the crack sealing truck can be tracked continuously as the truck moves forward to

position the cracks within the work space of the robot arms at the rear of the truck. At that point, the crack position data will be sent to the controllers on the robot arms (RPS) via the ICU. The robot controllers will then send signals to position the end effectors of the robot arms over the cracks. Once positioned, the end effectors will rout, clean, heat, and finally seal the cracks. It is our intent that ultimately the entire process of identifying the cracks, tracking their positions, positioning the robot end effectors, and performing the crack repair operation will be done in a continuous fashion with the truck moving ahead at a slow forward speed.

The entire VOC system will use digital communication. Two optical, rotary, incremental encoders will each be mounted on separate "fifth wheel" assemblies. The fifth wheel assemblies will be mounted on either side of the truck outside the rear wheels and between the two rear axles of the truck so the center line of the encoders passes through the center of rotation of the truck. The fifth wheel assemblies will continuously monitor the change in position of each side of the truck. From position data obtained from the encoders, the translation of the truck (laterally with respect to the road surface) and rotation of the truck (yaw - about a vertical axis with respect to the road surface) can be continuously calculated.

An on-board computer also will be a part of the VOC. This computer will serve several functions. In general, crack position data will be sent to the VOC computer from the VSS and truck position data will gathered from the encoders on the fifth wheels. Calculations of truck position and orientation and crack position (with respect to the truck) will be performed by the VOC computer, and this information will be shared with the ICU.

The VOC has been exercised on a movable cart to simulate motion on the actual ACSM. Based on preliminary testing minor modifications are being performed and the fifth wheel assemblies are in the manufacturing phase.

Local Sensing System

The purpose of the Local Sensing System is to locate crack position and measure crack width to a degree of precision such that the crack preparation, sealant application and shaping of the seal can be performed in an automated fashion.

On the general crack sealing machine, the LSS will work with the VSS to confirm the presence of a crack within a given area. The VSS will locate the approximate position of a possible crack using a video camera. This camera uses a line scan charged coupled device (CCD) as its sensing element. As the vehicle moves, lines across the lane width will be gathered to form an area view of the road surface. Through measuring the intensity of gray levels that the camera senses, it is possible to determine the position of possible cracks. However, since the line scan camera only has two-dimensional measuring capabilities, it may mistake an oil spot, shadow, or previously filled crack for an actual crack. The purpose of the LSS on the general machine is to scan the area near the potential crack location identified by the VSS to confirm or reject the presence of a crack. Furthermore, there are inherent inaccuracies in the VSS crack identification algorithm that gives it a resolution of approximately ± 1 inch. There are also errors associated with the motion of the vehicle that will result in errors in the crack location identified by the VSS. Therefore, the LSS also will provide more precise position information to the general Robot Positioning System (RPS). Local sensing will provide range information that can accurately sense the presence and position of a crack. However, local sensing alone would not be adequate because the local sensor requires a planned path to scan for random cracks. Because of the operating speed of the vehicle, the update rate and field of view of the local sensor are not adequate to track random cracks without prior knowledge of crack direction.

On the longitudinal crack sealing machine, the local sensor will provide all sensing information to the longitudinal RPS. Because the longitudinal cracks do not randomly vary in direction, it is possible to design a sensing system in which the local sensing system provides an error feedback signal to the longitudinal RPS. The start of the crack must initially be placed within the local sensor field of view, and then through real time controls and feedback provided by the local sensor, it will be possible for the longitudinal RPS to follow the longitudinal crack.

A variety of sensors technologies have been researched to select a sensing system that best meets the sensing requirements. The Local Sensing System that has been selected is the most cost effective, off-the-shelf component that meets all the requirements. The system selected is a laser vision sensor which measures range information using triangulation. Using triangulation, distance measurements are determined by transmitting a laser light source, then focusing the diffusely reflected light source on a photosensitive device. This method of detection is reliable and is commercially available and widely used for seam detection during automated welding.

Sensing systems based on triangulation are impervious to color variations. Therefore, a laser range finding sensor will work well on all pavements. Also, laser sensors are not sensitive to a dusty environment. Furthermore, laser triangulation is insensitive to lighting conditions because the sensor provides its own lighting via the laser. Overall, laser triangulation is a reliable technique for extracting three-dimensional surface characteristics.

To achieve optimal field of view and update rate from the sensor, a laser vision system using structured light was chosen. Laser vision systems based on structured light offer reliability, design simplicity, compactness, while maintaining cost effectiveness. Structured light extracts a three dimensional surface profile by projecting a laser pattern in a plane perpendicular to the surface being measures. The line of light is then observed by a CCD camera at an angle allowing the surface features to be found.

A commercially available sensor has been purchased which is simple to use and rugged in harsh environments. The sensor has a built-in heat exchanger for cooling and a cleaning mechanism that prevents dust from settling on the lens that would distort the image. These attributes are attractive given the harsh environment associated with automated crack sealing. The sensor itself is a small package weighing 9 ounces and measuring 4 by 3 by 1.6 inches. This package contains a laser light source, a CCD camera, and appropriate optics. The sensor will be mounted to the robot with a provided precision machined camera bracket. A vibration isolator will be placed between this bracket and the robot arm to protect the sensor from harsh vibrations and to prevent the image from being distorted. This system has been tested for performance on actual road surfaces, and additionally, it has been interfaced with a laboratory robot system to establish its adequacy for the ACSM.

Robot Positioning System

Our development approach has led to the development of two robot positioning system components, one for addressing longitudinal cracks off the side of the vehicle and one to address cracks off the rear of the vehicle. These systems are denoted as the longitudinal positioning system and the general positioning system, respectively.

For the general positioning system, a GMF A-510 SCARA manipulator and Karel controller have been purchased. The purpose of the manipulator is to guide process carts over pavement cracks as part of the general crack sealing machine. The GMF A-510 is a SCARA type four degree-of-freedom manipulator. Manipulators such as these are commonly used for assembly operations, food packing, and palletizing. Each joint is driven by a servo motor and the relative position of the joint is recorded by encoders. The servo motors and encoders are interfaced with the Karel controller. The A-510 manipulator was selected from a field of commercial manipulators on the basis of workspace, payload, and controllability.

The A-510 manipulator will be inverted and mounted on a linear slide on the back of the crack sealing truck. Figure 3 is a drawing of the manipulator-slide system as it will be mounted on the support vehicle. The Karel controller is a fully integrated robot motion controller that will be responsible for all motion of the manipulator. The controller will receive input from the LSS and the ICU that will provide it with necessary information to control the manipulator which in turn guides the process carts over cracks in the pavement. The Karel controller is able to use information from the encoders to move the end effector to locations within the workspace of manipulator. Pre-programmed information on the manipulator kinematics allows the controller to move the manipulator to points in Cartesian space about the base of the manipulator.

The manipulator has already been mounted on a custom built, servo controlled linear slide that is also integrated to the Karel controller. The slide has an overall width of 8 feet to fit on the back of the crack sealing truck, and it allows 2.5 feet of horizontal travel. The addition of the linear slide increases the reachable workspace of the manipulator and enhances its dexterity particularly near the edge of the workspace. A normal SCARA configuration manipulator cannot move along a given path within its workspace. In addition to extending the workspace, the addition of the linear slide provides a redundant degree of freedom which will allow the manipulator to move in any direction and along any path (e.g. following a crack) within its workspace. The slide-mounted A-510 and the Karel controller have been connected to a support structure within the laboratory for development purposes. As part of the preliminary testing so far, the LSS has been integrated and the entire system exercised. Additionally, path information has been successfully passed from the ICU to this system, and corresponding motion resulted.

The longitudinal RPS is the subsystem that carries the local sensor, the router, the vacuum and heater/blower ducts and the sealant applicator unit during operations on longitudinal pavement cracks running parallel to the roadway. The longitudinal

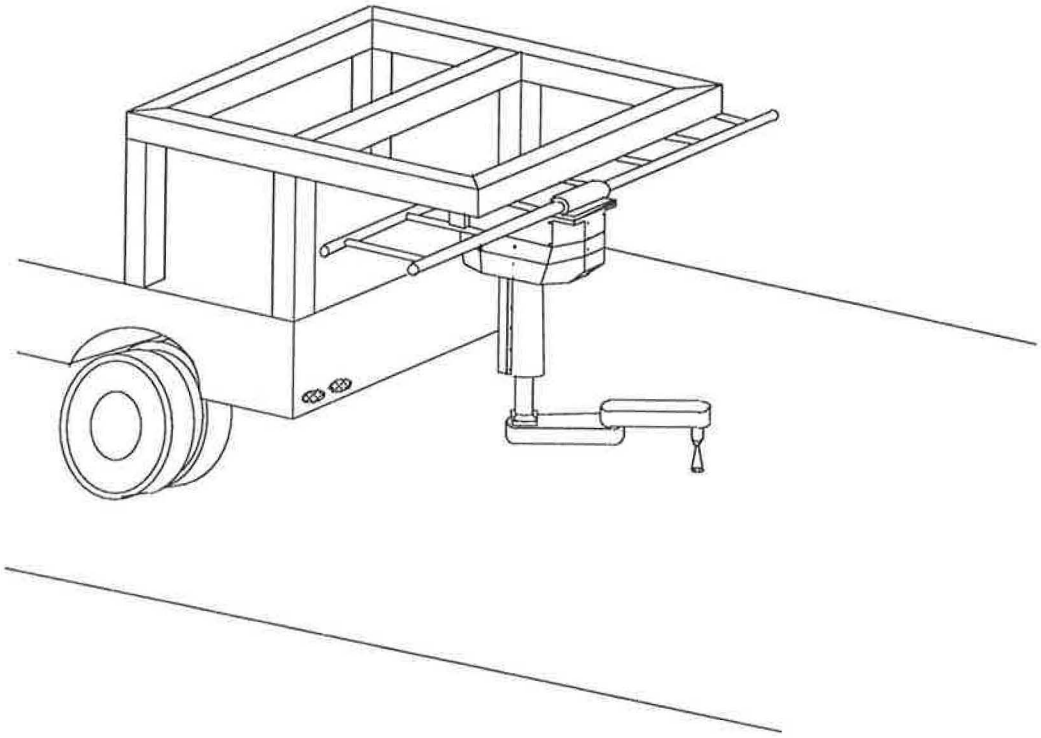


Figure 3 Drawing of the manipulator-slide system.

positioning system has two major component systems, the mechanical linkage structure that includes the end-effector cart, linear slide table, and the connecting links, and the actuator and control system. A commercially available prepackaged electro-hydraulic linear drive was selected for the actuator and control system consistent with our development philosophy.

The cart is attached to the side of the road maintenance vehicle with a mechanical linkage that allows the cart to move laterally a distance representative of crack geometry and driver capabilities as the vehicle is driven alongside the crack. The lateral movement is controlled automatically to correct for the relative position of the vehicle to the crack. The linkage also allows the cart to be retracted from the road when not in operation. Figure 4 shows the motion capabilities of the longitudinal positioning system. Figures 5 and 6 show the component configuration on the longitudinal RPS with and without the routing capability, respectively.

The following design features have been incorporated into the longitudinal RPS system:

- The actuator control system is simple. To accommodate this, the linkage allows the cart to translate laterally with the movement of the actuator.
- The linkage design is such that motion of the cart due to the changes in elevation and angle of the road surface result in the least possible lateral translation - which are compensated for by the actuator.
- Stowage is simple.
- A cart length of 5 feet is provided to allow installation of all APS components. Lateral movement of the cart is limited to 12 inches total, representative of operator's driving abilities.
- Designed for ease of application to any size support vehicle. The particular prototype built is dimensioned around the 40 inch high bed of the test vehicle made available to the project by Caltrans.

The first generation longitudinal positioning system, which does not include the automated positioning, has been delivered to Caltrans for on-road testing and debugging of the longitudinal RPS and the sealant applicator component. This testing will provide invaluable information on worker acceptance, quality of seal, ease in assembly on existing vehicles, and numerous other aspects all essential for commercialization.

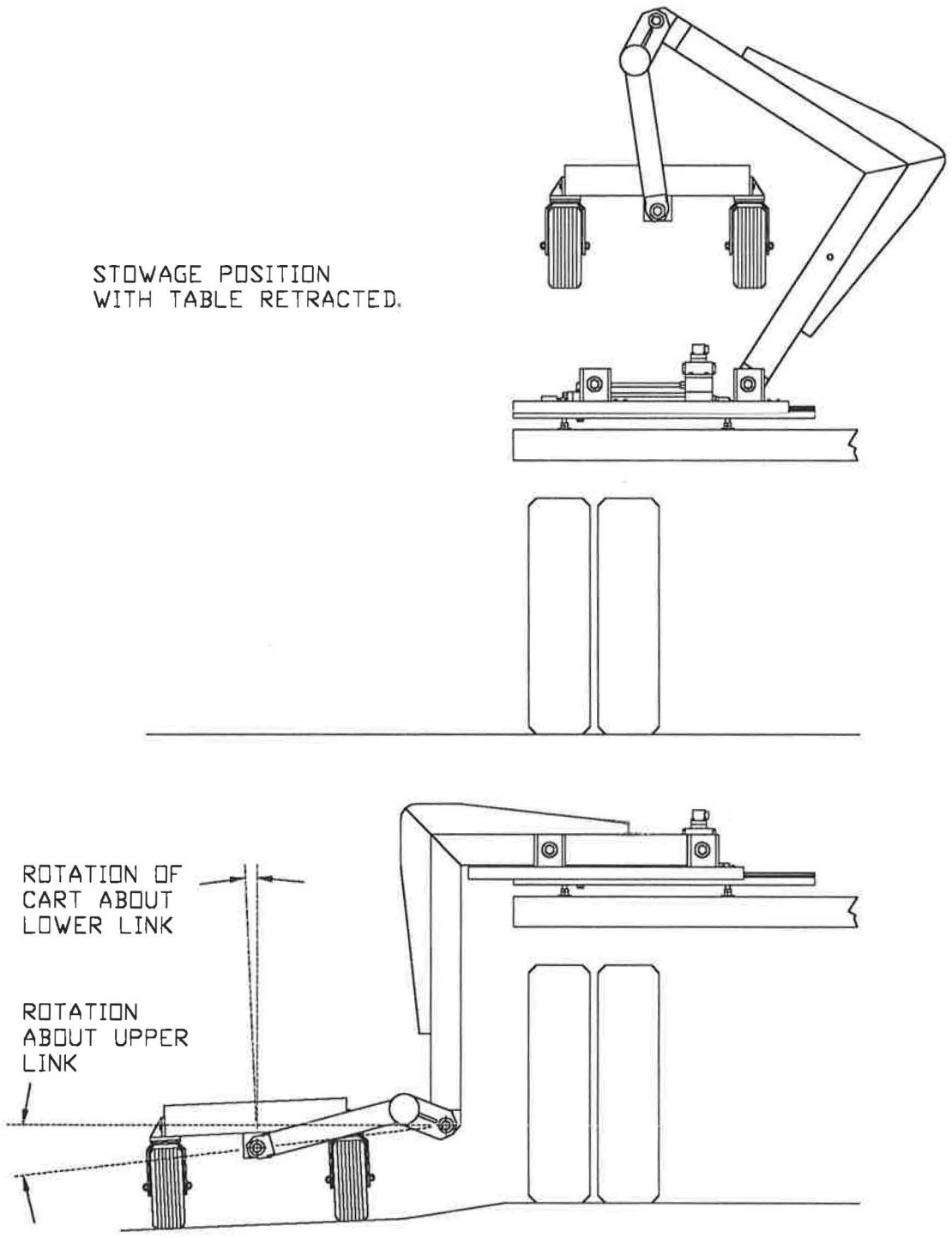


Figure 4 Drawing of the motion capabilities of the longitudinal positioning system.

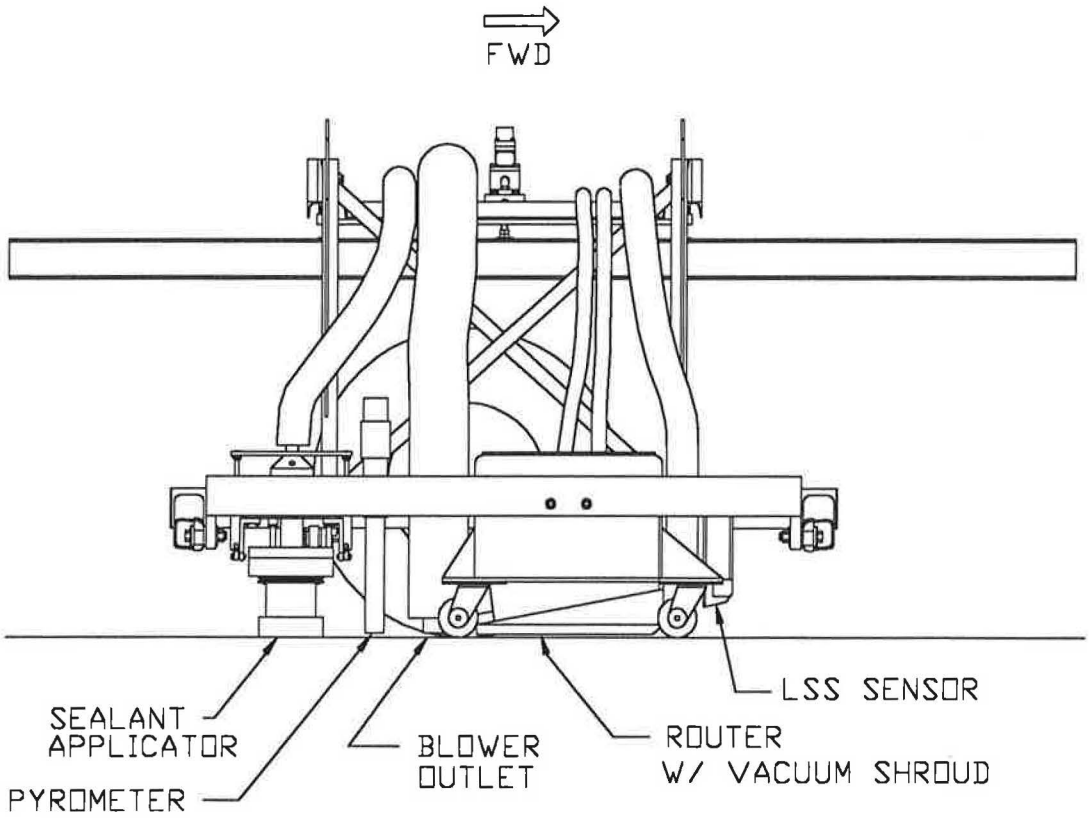


Figure 5 Drawing of the component configuration on the longitudinal robot positioning system with the router.

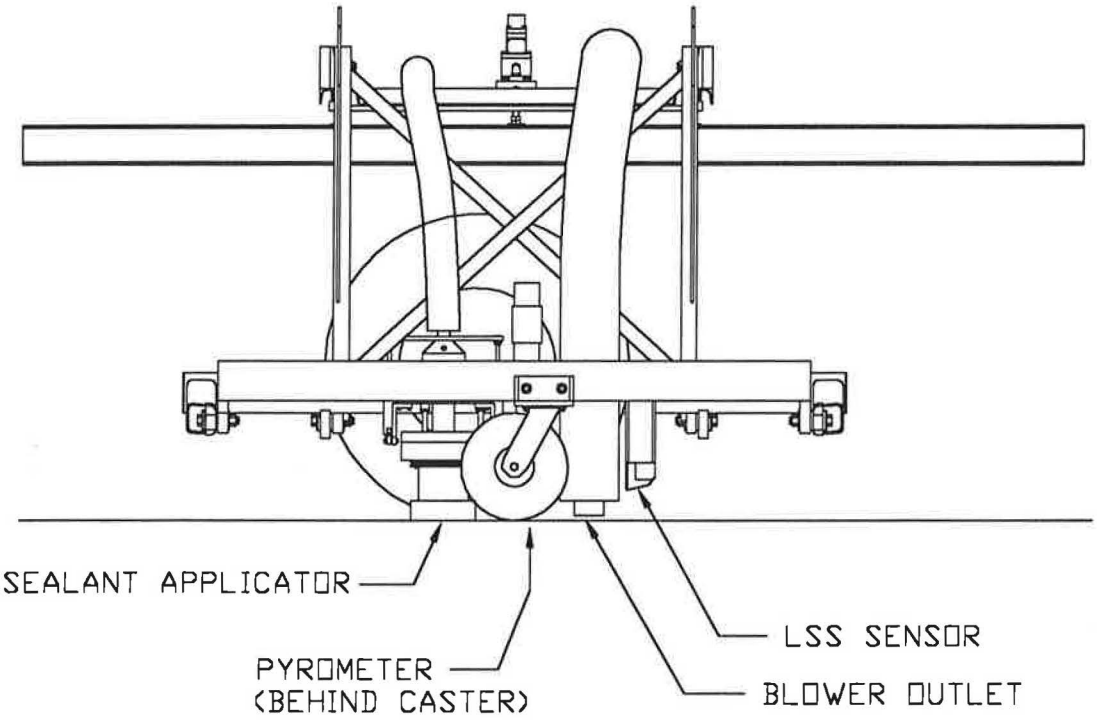


Figure 6 Drawing of the component configuration on the longitudinal robot positioning system without the router.

Applicator Assembly and Peripherals System

The key to sealed/filled crack/joint longevity is directly attributable to proper cavity preparation. Additionally, for most hot applied sealants/fillers, a uniform surface heating before application is desirable. While there are significant differences between the practices of the various states, for the widest possible applicability, an automated machine also must allow for pavement routing. The Applicator Assembly and Peripherals System prepare the crack/joint and applies and finishes the sealant.

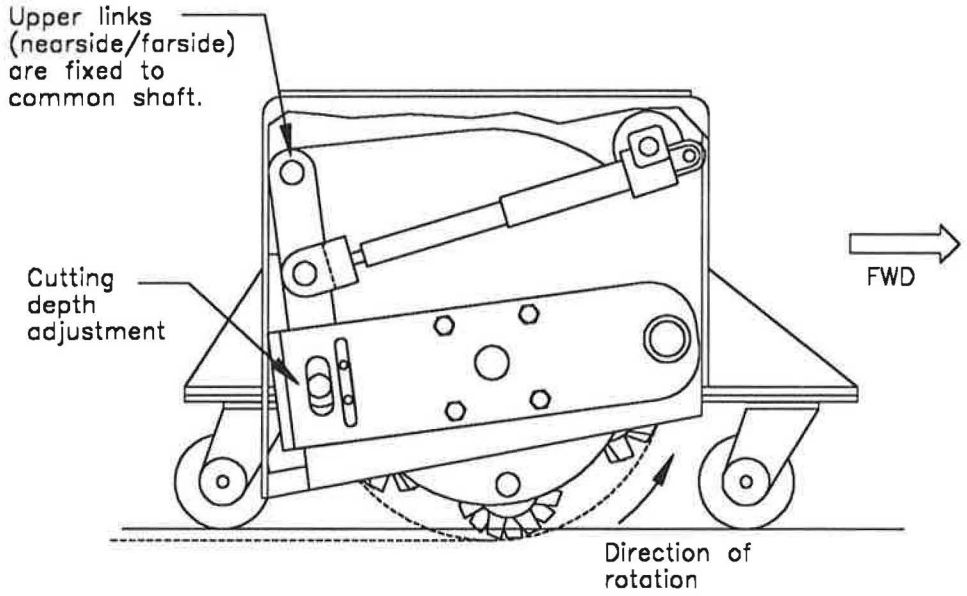
Recent studies(*1*) have shown that the ideal method for crack preparation should include the use of a two phase hot air system. The primary phase of this system should include a source of high temperature and high velocity compressed air to remove entrapped aggregate/ vegetation and moisture. The second phase of the heating system should be used to warm, to approximately 280°F (based on recent studies at Caltrans), the surrounding horizontal crack margins to ensure a highly adherent bond between the surface and the sealant material. Once the crack is cleaned, dried and heated, a suitable sealant can be applied. The desired patch configuration requires moderate penetration of sealant material into the vertical crack surface, and sealant penetration can be sharply increased as the temperature differential between the surface and the sealant material is minimized. Thus, we have been developing routing, heating/cleaning/debris removal, and dispensing components for the ACSM, and we will now address each of these components.

The router is used to prepare cracks by cutting a channel along the crack in a profile that allows for increased penetration and adhesion of the sealant. The router was developed to accommodate the unique requirements imposed by the automated crack sealing machine. The design uses an existing impact router cutting wheel installed in a configuration that will follow random cracks with the general purpose RPS or the nearly linear cracks with the longitudinal RPS. It is hydraulically powered which allows it to be operated with a remote power supply. As a result, its size and weight are minimized to best accommodate its use with the RPS systems. In addition, the design allows for cutting at the increased speeds necessary for the automated crack sealing applications. The impact cutter design allows for variations in cutting depth and width that can be adjusted by placing the individual cutting wheels in various configurations. Adding cutters and increasing the rotational speed of the cutting wheel assembly also allows for operation at higher road speeds. The router component is a modular unit that will operate in both systems with minor modifications.

The routing component consists of a commercial impact cutting wheel mounted in a frame supported on casters. The weight of the router unit is supported entirely by its wheels and the wheeled frame is designed to resist all forces that act to upset the cart during operation including forces from the RPS to which it is attached. The cutting wheel holds six rows of cutters and is designed to run at 2000 RPM. The cutters have a diameter of 4.75 inches and the total effective cutting diameter of the wheel is 15 inches. The maximum cutting width of this wheel is 2.25 inches, limited by its cutting wheel design. A linear drive is incorporated to extend and retract the cutting wheel. A debris shroud from the debris removal system will be attached to the bottom of the router shroud. It includes a deflector plate forward of the cutting wheel that directs the debris to the vertical tube attached to the vacuum line of the debris removal system.

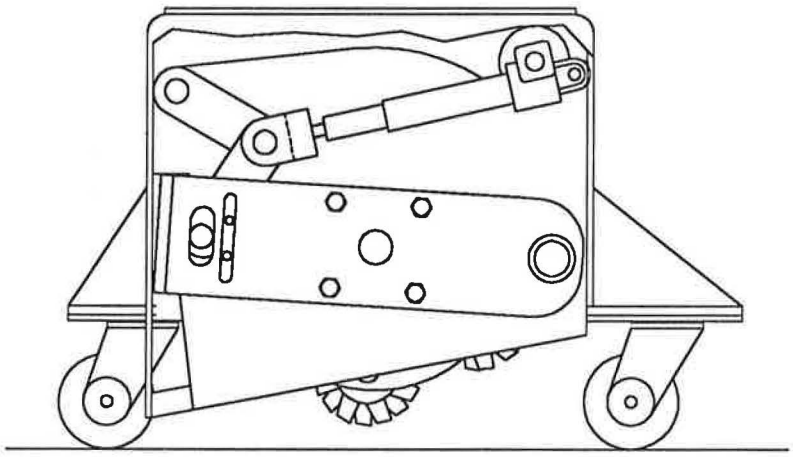
The basic principles of impact router operation have been verified on a manually operated commercial routing unit. The operator, while walking backwards and pulling the machine, guides the unit by observing the cutting wheel as it follows the crack. Debris is thrown in the direction away from the operator. This mode of cutting runs the cutter wheel in a "down-milling" cut direction. Testing showed that the router tended to pull itself up out of the road bed when operated at higher surface speeds. By pushing the router, which results in a conventional "up-milling" cut, the operation of the router is considerably smoother. Greater force is required push the unit since the resulting cutting force acts in the direction opposite the direction of travel. However, a significant advantage is that the routing machine does not pull itself out of the roadway when "up-milling." Test results determined that operating the router in the conventional "up-milling" mode was the most efficient and would be used for the APS router component. This option is not possible with the manually guided machine since the debris would be thrown toward the operator. The router has been built and tested on actual pavement, and it is ready for installation on the final prototype machinery. Figure 7 is a schematic of the router.

The heating, cleaning and debris removal (HCD) subsystem includes: a debris separator, a 5 PSI, 400 SCFM hydraulically powered centrifugal blower, a 692,000 BTU/hr Thermal Blast Heater, and an infrared pyrometer to measure crack temperature and thereby modulate fuel flow to the burner. Overseeing safe



Router cutting wheel extended for cutting. Cutting depth shown set at mid–range.

(View is cutaway of wheel support frame and does not show dust collection shroud.)



Router cutting wheel retracted.

(View is cutaway of wheel support frame and does not show dust collection shroud.)

Figure 7 Schematic drawing of the router.

operation of the burner is a standard flame safeguard control panel that features additional control panel functions for diverter valve actuation (to ensure safe idle operation), CLEAN ONLY operation (no heat), and a PID controller to interface with the pyrometer. The debris removal portion of this system consists of a debris shroud mounted to the router casing, the separator unit and waste container located on the truck bed, and flexible hoses. The blower provides vacuum air to the debris shroud and separator unit and the waste container houses all collected debris for later disposal. Both the blower and burner units are to be located on the truck in a location that minimizes pressure and heat losses through minimal bending and plumbing distance. Proper insulation will protect subsystems and operators from danger. Hydraulic power to the blower is provided by the central hydraulic system. The pyrometer is located aft of the burner exhaust nozzle on the longitudinal sealant cart and between the sealant applicator and heater nozzle exit on the general process cart. This system has been designed based on detailed heat transfer analysis, and extensive testing of existing blowing and heating units. Again, this system is comprised of commercially available components.

The sealant applicator unit constitutes a significant advancement in crack sealing technology. It was designed to deliver hot thermoplastic sealant at an increased velocity over current crack sealing techniques, as well as shape the material to produce a variety of sealant finish configurations. A significant advantage this unit possesses over other sealing methods is that it uses a small amount of pressure to force sealant into the crack. The sealant flow rate is automatically adjusted according to the cross-sectional area of the crack. The unit is designed for operation in both positioning systems. The sealant applicator is being tested by Caltrans in the longitudinal RPS. Figure 8 is a photograph of the sealant applicator.

Path Planning Module

Based on the importance of the path planning of the robot positioning systems (i.e., how identified cracks will be addressed by the RPS), the Path Planning Module, which actually is software internal to the ICU, is considered an independent subsystem. The path planning routine must convert the processed vision data from the VSS into a format that is usable by the RPS. The essential tasks are to find connected components, and plan a path for the manipulator for the individual crack segments in a frame. Due to constraints on the VSS hardware and software, there will generally be missing segments on a given crack. One task of path planning is to connect segments together, subject to a minimum separation criterion. The fundamental path planning algorithm includes: converting VSS data into array; growing crack data to connect regions, subject to minimum separation specification; thinning the resulting data using some form of medial axis transformation (MAT), scanning the final array data for connected cracks, and converting to RPS format. The RPS format consists of a list of x,y coordinates, and an associated orientation for the manipulator end-effector. This list will be sent by the ICU over a serial line to the RPS, after it has been transformed using the VOC data. The code for this algorithm is working on a Silicon Graphics workstation, as well as on an IBM PC, and it is able to plan a path for a single crack.

CONCLUSIONS

This paper has discussed progress towards the development of an automated machine for the sealing of cracks in pavement. Such machinery is being developed under the sponsorship of the Strategic Highway Research Program (SHRP H-107A) and the California Department of Transportation Office of New Technology and Research. Significant components of this machine have been and are being tested, the integrated prototype machine will be field tested late in 1992. A machine to address only longitudinal cracks and joints, such as construction joints running along the direction of travel of the highway, is being field tested by Caltrans personnel.

REFERENCE

1. Rossman, R.H., H.G. Tufty, L. Nicholas, "Value Engineer Study-Repair of Transverse Cracking in Asphalt Concrete," FHWA Final report, 1988.

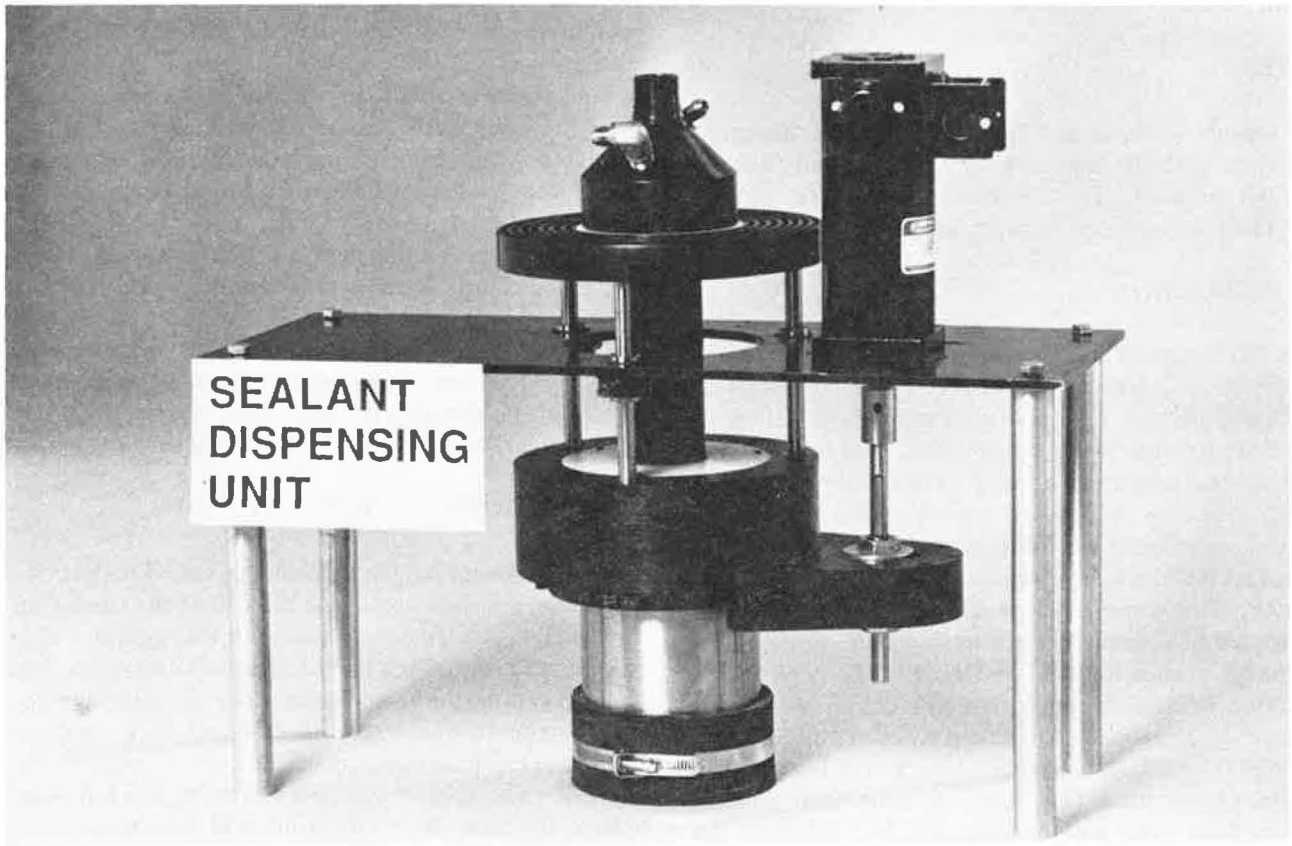


Figure 8 Sealant applicator/dispensing unit.

REMOTE DRIVEN VEHICLE

Mark Smith, *ENSCO, Incorporated*

SCOPE

This paper outlines the Strategic Highway Research Program (SHRP) sponsored Remote Driven Vehicle (RDV) project. The function of the RDV system, including the technical aspects, are summarized.

INTRODUCTION

The RDV concept is intended to reduce highway worker fatalities by removing the drivers of shadow vehicles from the driver's seat and placing them at a remote roadside location in the work-zone. The driver would control the vehicle by a small control console that is radio linked to the shadow vehicle. With the control console, the driver has full control over the vehicle.

The RDV concept was developed as a product of SHRP. This concept was motivated by ever increasing incidence of highway worker fatalities due to collisions involving shadow vehicles. In December of 1990, SHRP directed ENSCO to implement the design of a RDV vehicle. Minnesota Department of Transportation (MnDOT) participated by donating a new 1990 FORD L8000 Dump truck (see figure 1) from their maintenance fleet. Ten months later, ENSCO delivered the prototype RDV to MnDOT. This system is currently being used by MnDOT in the field where data is being collected for the development of a second generation system and overall concept evaluation.

The RDV system consists of a set of actuators, digital control circuits, a radio link and sensors to provide for the remote control of trucks that are being used as shadow vehicles. The system can be installed without extensive modifications to most shadow vehicles. Basic premises of the system are durability and safety. The RDV system has multiple levels of safety systems to reduce the possibility of accidents due to equipment failure.

A second generation design is in the planning stages. It eliminates the central control computer and replaces it with a digital logic board. This reduces the system cost, enhances reliability, and simplifies maintenance. With the second generation system, it should be possible for state maintenance agencies to purchase the basic system in kit form and adapt it to their shadow vehicles.

DESCRIPTION OF THE RDV SYSTEM

The RDV system has the following layout. An electronic enclosure is mounted inside the cab of the truck (see figure 2). This enclosure contains the system safety circuits, and controllers for the actuators and any power supplies that might be necessary. The electronic equipment inside the enclosure is designed in a modular fashion to facilitate maintenance and enhance reliability.

The radio control system implements the following vehicle functions from the hand-held transmitter (see figure 3):

- steering - full steering from lock to lock
- brakes - proportional brake control
- throttle - controls vehicle throttle throughout it's whole range

Figure 1 MnDOT Ford L8000 Truck.

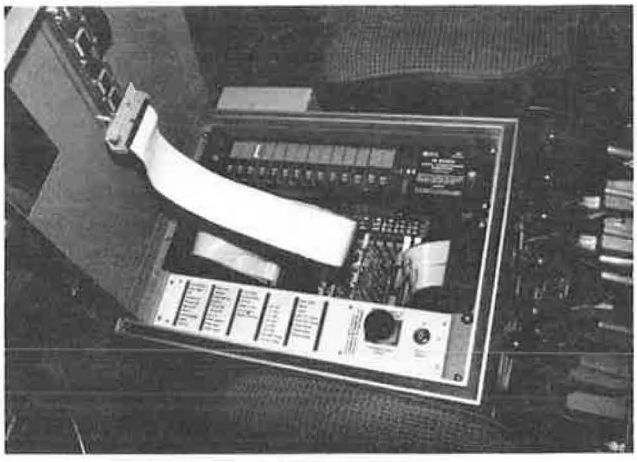


Figure 2 Electronic enclosure between front seats.

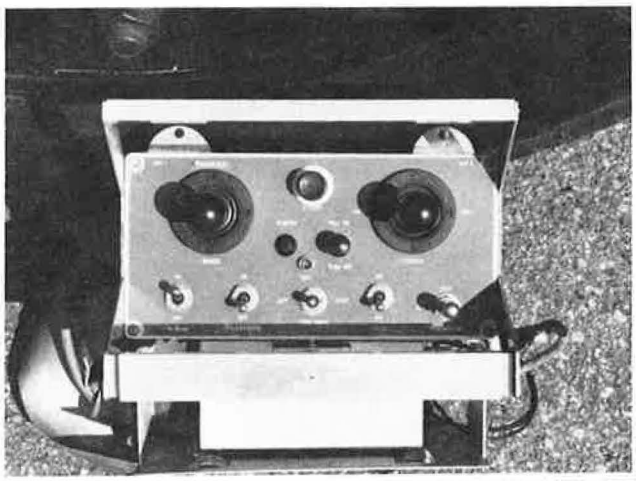


Figure 3 Hand-held transmitter.

- transmission - three position switch for neutral, park and drive
- horn
- headlights
- parking brake
- flashers
- emergency stop
- turn signals

Functional Requirements

The following requirements are built into the RDV system:

- The equipment installed on the truck does not impair the function of the driver controls while the truck is being driven in a normal manner.
- The RDV system is protected against aberrant behavior such as power failures and air pressure loss. The braking system stops the truck automatically in case there is an air pressure loss or electrical power failure.
- The RDV system has an all weather capability from 20°F to 110°F. All external components are corrosion protected from road salt.
- The system electronics are modularized to allow for the quick replacement of a defective subsystem.
- The radio transceiver system has a range of 1000 feet. It is battery operated and uses rechargeable batteries.
- The RDV system has proximity sensors that detects objects that are 15 feet in front of the truck.

Pneumatic System

All the actuators are pneumatically driven with position feedback for closed loop control. These actuators use the truck's air supply system that is modified to deliver a minimum of 100 psi. The RDV system is integrated into the truck's air brake system. In case of emergency conditions or equipment failure, the spring brakes on the truck activate automatically. An electrical failure or system pressure loss also will activate the spring brakes making the RDV system inherently safe.

Safety Equipment

The truck's oil pressure, coolant temperature, and engine run status are constantly monitored to preclude any system damage. The emergency brake system is designed such that regardless of either an air pressure loss or an electrical power failure, the emergency brake system engages.

The safety system is multi-layered. Primary protection safety is provided by the emergency stop hardware circuit. If this circuit finds any error conditions with the truck, the emergency stop system is engaged. If there is a communication problem with the radio equipment, the truck will stop. Sensors in front of the truck sense objects and stop the truck if they detect some obstruction. On both sides of the truck are large push-button switches that are pressed to stop the truck. These switches work with the emergency stop button on the transmitter. If the operator trips and falls, a tilt-switch inside the transmitter will detect this and stop the truck. The last level of protection is built into the mechanical equipment. If there is an electrical power failure or an air pressure loss in the system, the air control valves will default to a position that will engage the emergency stop spring brakes. Overall, the system is designed to preclude any accidents due to equipment failure.

Reliability

The RDV is designed for enhanced ruggedness and reliability. All actuators are of premium industrial quality and tolerant of salt spray environments. Second generation systems will have the following enhancements:

- All connectors will have a 1000 hours salt spray rating.
- The enclosures will be gasketed and will be constructed out of fiberglass, aluminum, or stainless steel.

- Wire runs between equipment will be minimized.
- Electronics will be mounted on circuit cards for added strength and rigidity.

In case of circuit failure, the primary circuit card can be replaced by removing the card and inserting a replacement card.

Transmitter/Receiver

The transmitter/receiver has extremely sophisticated anti-interference protocols. The transmitter is powered by ni-cad batteries and is supplied with a battery charger that will reside inside the cab of the truck. This charger will continuously charge the spare battery in case it is required. Currently, the transmitter has two joysticks for controlling throttle, brakes, and steering. The second generation transmitter will have a single joystick for controlling throttle, brakes and steering. The transmitter will be designed to be handheld but will have a shoulder harness and chest strap for securing the unit to the operator.

SYSTEM USAGE

The RDV system is used in the following manner. The shadow vehicle is placed a couple of hundred feet behind the work-zone with a message board. As the work crew moves along the work-zone the shadow vehicle is moved forward with the RDV system. Typical operation scenarios are pothole filling, crack sealing and trash pickup. The current RDV in the remote operation mode has a maximum speed of 5 mph so normal walking speed is easily attained.

FUTURE PLANS

It is envisioned that the RDV system capabilities be expanded by making it completely autonomous. This would entail using a vision system to follow a lead vehicle. This system would be appropriate for snow-plowing, line painting and other fast moving highway maintenance operations. Several prototype systems are currently available but are not yet cost effective.

PORTABLE EQUIPMENT TO MEASURE THE EFFECTIVENESS OF MAINTENANCE TREATMENTS

Brian E. Cox, *Strategic Highway Research Program*

BACKGROUND

A major part of Strategic Highway Research Program's (SHRP's) Highway Operations Research is concerned with preventive maintenance. For many years, I was a Maintenance Manager in the U.K. with responsibility for the maintenance of highway networks ranging from heavily trafficked national roads to lightly trafficked farm to market roads. I know, like others before and since, from practical experience that a stitch in time does indeed save nine and that preventive maintenance treatments, such as chip seals, thin overlays or slurry seals, if applied at the opportune time, can prolong the life of pavements.

INTERVENTION

The question is, what is the opportune time? I've known Engineers who have maintained that a sealcoat should be laid two years after a surfacing has been laid. I've known other Engineers who have said, with equal conviction, that preventive maintenance is most effective if applied after the first micro-crack has appeared. The general practice seems to be to wait until there is noticeable deterioration, although I'm sure there are many other ideas.

SHRP Project H-101 is aimed at providing a definitive answer - the optimum time to intervene with a preventive maintenance treatment to maximize maintenance cost-effectiveness. The optimum time will be related to a stage in the deterioration of the pavement structure, for which a condition, such as surface cracking, may be symptomatic.

CONDITION MEASUREMENT

Project H-101 will define the condition that should trigger preventive maintenance action. Project H-104 is concerned with the development of devices to measure that condition. When we started on this road, our panel of experts agreed that preventive maintenance was likely to be most effective when carried out at a very early stage in the deterioration of a pavement. From that opinion, we concluded that we probably needed to be able to measure small symptoms of distress.

Our preliminary research showed that at present there isn't equipment that can do that, and indicated that we might well need to be able to measure hidden conditions, such as changes in base moisture content that could increase the flexure of the pavement and thus the incidence of fatigue cracking.

The sort of conditions that we became interested in measuring were:

- Moisture in the foundation layers beneath a flexible surface
- Moisture under rigid pavement joints
- Moisture within an asphalt layer
- Fine cracking
- Subsurface problems
- Voids or loss of support under rigid pavement joints
- Overlay delamination
- Asphalt Aging

The preliminary research confirmed that there were technologies that could be used to detect and measure those conditions so we advertised for proposals and were able to select two proposals that in consort offered the prospect of both problem detection and diagnosis.

OBJECTIVES

The objectives of Project H-104 are straightforward. They are to help the Maintenance Engineer to determine:

- the need for preventive maintenance treatment,
- where it should be carried out,
- the effectiveness of preventive maintenance treatments, and
- the status of the preventive maintenance experiments.

NETWORK LEVEL

On April 1, 1990 a research contract was awarded to Geophysical Survey Systems, Inc. to develop equipment utilizing ground penetrating radar (GPR) technology that could be used to survey a whole highway network.

The concept is an advanced form of radar mounted on a vehicle or in a trailer which, travelling at highway speed, would detect and measure:

- Moisture in the foundation layers beneath a flexible surface
- Moisture under rigid pavement joints
- Voids or loss of support under rigid pavement joints
- Overlay delamination
- Moisture within an asphalt layer (stripping)
- Subsurface problems

PROJECT LEVEL

At the same time, a research contract was awarded to the University of Texas at El Paso to develop equipment using seismic technology that could be used at a project level. The Seismic Pavement Analyzer utilizes wave propagation technology to perform detailed diagnosis of pavement conditions.

The conditions to be diagnosed include:

- Moisture in the foundation layers beneath a flexible surface
- Moisture under rigid pavement joints
- Voids or loss of support under rigid pavement joints
- Overlay delamination
- Fine Cracking
- Asphalt Aging

NETWORK VS. PROJECT LEVEL

As an example of the different level of information to be provided by the two types of equipment, whereas a ground penetrating radar survey of a highway network might provide the location of overlay delamination, the Seismic Pavement Analyzer will convey the difference in pavement performance at specific locations through the change in pavement modulus. The radar equipment can be used for rapid problem detection over a roadway network. The pavement analyzer is a stationary device that provides on the spot detailed diagnosis and thus the two devices are complementary.

CRITERIA FOR EQUIPMENT

The intention is that in both cases the equipment should be operable by maintenance technicians from a district office. Consequently, it has to be serviceable and user friendly.

When we were drawing up our shopping list of wants, our panel of experts, made up mostly of maintenance engineers from state DOT's, leavened by specialist technical expertise, advised that the equipment should be:

- Portable e.g., mobile and easily moved
- Reasonable cost
- Easy to use and interpret results - A current drawback of this type of technology is that it requires expert interpretation.
- Easy to calibrate
- Reliable and reasonably quick to use
- Rugged

PROGRESS

So, how are we doing? We are now in the third year of development and the research contractors are designing and building second generation (near commercial) prototypes. It should be recognized that we're trying to do something that hasn't been done previously. Even the definition of what we're looking for is vague and requires more research to tie down the cause and effect, such as, for example, the ingress of moisture through fine cracks in the pavement surface and the consequent softening of the base. We're also working, in advance of the findings of the preventive maintenance experiments, on the conditions that should trigger preventive maintenance treatment.

We spent a year on the feasibility stage, trying to determine the criticality of condition measurements to establish targets for the devices, clarifying the measurement concepts for the specific devices and verifying the concepts at the laboratory level.

In the next year, the contractors built and tested first generation prototype devices. They need to be tested and calibrated for specific condition states. However, pavement conditions can vary widely, and the true situation can prove very difficult to establish. Consequently, a full scale outdoor test facility with built-in defects of known dimensions was constructed at the University of Texas at El-Paso to allow controlled testing.

At the moment, we're hoping that all the problems that we found in the second year field testing will be overcome by the improved second generation devices, and by January 1993, we shall know that reliable, readily understood information can be produced from the pavement measurements.

DEMONSTRATIONS

Of course it's no good building a better mouse trap if nobody knows about it! So, as well as the states in which the proof testing will be taking place later this year, we shall, from January to March next year, take the equipment around the country and demonstrate its operation to State DOT'S. There will be the opportunity for hands on experience and feed back from the potential users on the usefulness of the equipment.

CHEMICAL SPREADERS FOR ANTI-ICING APPLICATIONS

L. David Minsk (Retired), *Strategic Highway Research Program*

Like a bloated sumo wrestler in an all-you-can-eat restaurant, we have not learned to push away from the table salt and have a near-insatiable craving for the white stuff on our roads. Though it is unlikely we can kick the habit completely (after all, it's cheap and effective), one of Strategic Highway Research Program's (SHRP's) objectives is to put the country on a diet--reducing the amount of deicing chemicals.

One approach initiated in 1991 is the development of anti-icing technologies. Anti-icing, as contrasted with deicing, involves the application of a freezing point depressant on the pavement before the onset of precipitation, or at the latest during the very early stages of a freezing precipitation event. The potential for reduced chemical application lies in the fact that once snow or ice falls on an untreated pavement, there is a very high probability of a strong mechanical bond developing between the snow or ice and the pavement that requires excessive quantities of chemical to remove--the chemical must penetrate the frozen mass to reach the pavement interface to dislodge the ice. An anti-icing treatment, on the other hand, prevents the ice or snow from developing that strong bond, thus facilitating mechanical removal by plowing or traffic action.

In cooperation with nine participating states (CA, CO, MD, NV, MO, MN, NY, OH, WA), field observations were conducted during winter 1991/92 at 15 sites in four climatic regimes. Each site included a test section where an anti-icing treatment was applied, and a nearby control section where the conventional deicing approach was followed. Anti-icing treatments included reduced application rates of the state's conventional treatment, or prewetted salt or liquid magnesium chloride. Because an informed decision on when to start applying an anti-icing chemical is based on the best available weather forecast, sites were selected where either site-specific weather forecasts were provided from a contract meteorological service or where road weather information systems were installed, or both. However, the mild winter resulted in only 51 storm events recorded in seven of the states.

Since one of SHRP's objectives is the application of low quantities of chemical that may be below the capabilities of current agency application equipment, the Minnesota Department of Transportation is evaluating current equipment capabilities as a subcontractor to SHRP's prime contractor, Midwest Research Institute. A third contractor, Michigan Technological University's Keweenaw Research Center, is conducting controlled tests on an unused airport runway to assess the effectiveness of several chemicals, in liquid or solid form and at two application rates, in terms of their effect on friction as a function of time. Friction is measured using a Saab Friction Tester every 15 minutes after chemical treatment for up to two hours. Limited trafficking is performed to simulate highway conditions.

Some results of the spreader equipment testing has been provided by the MnDOT. In the absence of any recognized protocol for evaluating spreader performance, MnDOT has embarked on an effort to develop one. Several variations of areal distribution measurement have been tried. Catching the salt leaving the spinner in pans laid in rows normal to the direction of truck travel is one (Figure 1). Another dispensed with the pans and merely collected the salt in marked areas either by hand-sweeping or by vacuuming with an industrial vacuum cleaner. The principal finding in these exploratory tests has been that the distribution of the salt spread by a spinner is exceedingly non-uniform, and varies with speed of the truck. The results of a test on one spreader operating at three trucks speeds (14, 20, and 25 mph) is shown in Figure 2. Though windrow, stripe, or band spreading of salt or other chemicals is an acceptable and useful technique for deicing, it is not the preferred method for anti-icing. Anti-icing is most effective when chemicals are applied uniformly on the pavement. This work is expected to result in recommendations for selection of effective equipment and for design of improved devices.

Figure 1 Pans laid in rows normal to direction of truck travel to catch salt leaving the spinner.

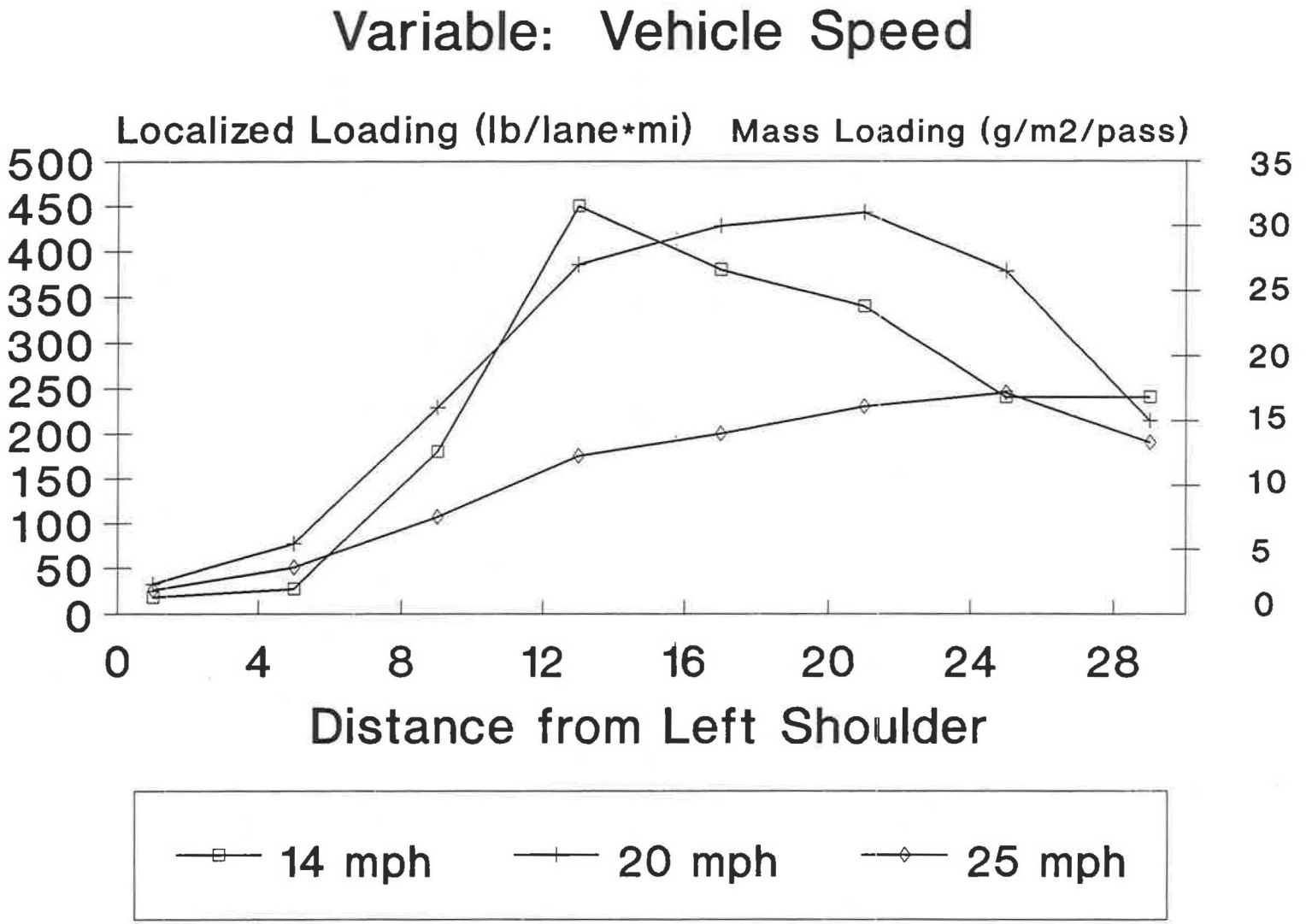


Figure 2 Changes in chemical spread pattern at different truck speeds.

DEVELOPMENT OF PERFORMANCE SPECIFICATIONS FOR TRUCK MOUNTED ATTENUATORS (TMA's)

Lindsay I. Griffin, III, *Texas Transportation Institute*

INTRODUCTION

In June of 1989, the Texas Department of Transportation (TxDOT) contracted with the Texas Transportation Institute (TTI) to develop a set of performance specifications for truck mounted attenuators (TMA's). The objectives of this project were to (1) assess the performance of several truck mounted attenuators and then (2) develop and propose the criteria that define an "acceptable" TMA. These criteria will be used by the Equipment and Procurement Division (D-4) in setting minimum performance requirements for TMA's purchased by the TxDOT.

The findings from this study are detailed in a final TTI report which is composed of three volumes:

- *An Evaluation of Selected Truck Mounted Attenuators with Recommended Performance Specifications* by L.I. Griffin, R. Zimmer, W.L. Campise and K.K. Mak
- *Comparative Crash Tests Conducted on Seven Different Makes and Models of Truck Mounted Attenuators (TMA's)*, by Wanda L. Campise
- *Procedures and Equipment for Conducting Vibration and Moisture Tests on Truck Mounted Attenuators (TMA's)*, by Richard A. Zimmer

This paper provides an overview of the work performed during this project, and the conclusions and recommendations drawn from that work.

PROCEDURE

At the outset of this study a decision was made by TxDOT and TTI to evaluate a candidate set of TMA's currently on the market (or under development) on three basic performance criteria. Although other criteria might have been considered in evaluating the performance of TMA's (e.g., flammability), the three criteria listed below were thought to be of primary importance:

- Crashworthiness: (a) How much protection is afforded drivers of vehicles that impact TMA's? (b) To a lesser extent, how much protection is afforded drivers of the dump trucks to which TMA's are attached?
- Fatigue: How well do TMA's "hold up" in real-world operations? How well do TMA's withstand vibrations typical of in-service usage over protracted periods?
- Moisture Resistance: How susceptible are TMA's to collecting moisture during inclement weather – particularly if the collection of moisture might be expected to denigrate the crashworthiness of the TMA?

To conduct the crash, vibration and moisture tests, TTI was provided with seven different makes and models of TMA's (three units per make/model). The specific makes and models provided are listed below.

- Energy Absorption Alpha Model TMA
- Energy Absorption Hexfoam Model TMA
- Hexcel Current Model TMA
- Hexcel Developmental Prototype TMA
- Renco TMA
- Markings and Equipment Corporation TMA
- Connecticut DOT TMA

Crash Testing

During this study, 21 different crash tests were conducted. These tests served (1) to assess the overall benefit of TMA's (relative to similar tests in which no TMA's were used) and (2) to compare the performance of individual makes and models of TMA's with respect to one another.

The TMA's evaluated were mounted on a 24,000-lb (GVWR) dump truck that had been ballasted to 14,000 pounds before the attachment of the TMA. Each test was conducted in general accordance with guidelines presented in NCHRP Report 230.*(1)* The 21 crash tests were divided into four test series:

- Test Series 1: Eight tests were conducted using a 4,500-lb passenger car impacting the TMA head-on at 45 mph with the dump truck in a free-standing position in second gear with the parking brake on. For comparison, an additional (ninth) test was conducted under the same impact conditions without a TMA.
- Test Series 2: Seven tests were conducted using an 1,800-lb passenger car impacting the TMA head-on at 45 mph with the dump truck in a fixed position with its front bumper against a rigid wall. For comparison, an additional (eighth) test was conducted under the same impact conditions without a TMA.
- Test Series 3: Three tests were conducted using a 3,500-lb passenger car impacting the TMA head-on at 55 mph with the dump truck in a free-standing position in second gear with the parking brake on.

- Test Series 4: One test was conducted in this series. The conditions for this test were equivalent to the conditions in Test Series 1, except that the striking vehicle was a 4,500-lb pickup truck instead of a 4,500-lb passenger car.

The results of these four series of crash tests are summarized in three figures: Figure 1 (Test Series 1 and 4); Figure 2, Test Series 2; and Figure 3, Test Series 3.

All seven of the TMA's evaluated in Test Series 1 were acceptable. That is, during the collision, all seven cushions displayed occupant impact velocities of less than 40 ft/sec and longitudinal ridedown accelerations between 0 and -20 g's. The one test conducted in Test Series 4 was also found to be acceptable.

In Test Series 2, two of the seven cushions that were tested had occupant impact velocities greater than 40 ft/sec. Two others had longitudinal ridedown accelerations below -20 g's.

In Test Series 3, all three TMA's had acceptable occupant impact velocities, but unacceptable longitudinal occupant ridedown accelerations.

Vibration Testing

In the TTI vibration test, TMA cushions are mounted to a vertical, 0.5 inch steel plate. The plate is sinusoidally oscillated up and down at 7 Hz through a total displacement of 0.6 inch for approximately 1,000,000 cycles (40 hrs). The 40-hour vibration test typically takes place over 4 or 5 days of testing, 8 to 10 hours per day.

When TMA's are tested on the TTI fixture, they are in a horizontal position. TxDOT has an established policy that TMA's should be in the "down" or "horizontal" whenever they are operating in traffic, regardless of whether or not they are shadowing (i.e., protecting) a maintenance operation. After the TMA is attached to the test fixture, it is vibrated for a few minutes to ensure that any slack in the system (i.e., in the TMA or in the connection between the TMA and the test fixture) has settled out. Then a reference point is marked on the left and right rear corners of the TMA cushion. The heights of these points are measured, relative to the ground. At periodic intervals the heights of the reference points are remeasured to determine if the unit is "sagging" due to fatigue or structural failure. An evaluation form is completed each time the reference points are remeasured. In addition, any cracks, fractures, popped rivets, broken bolts or pins, etc. that appear during testing are noted and photographed.

Those TMA's that sagged more than 0.5 inch during a 40-hour test were tentatively defined as unacceptable. Of the five TMA's subjected to the TTI vibration test procedure, three were judged acceptable by this criterion (Energy Absorption Alpha, Hexcel Current Model, and Markings and Equipment Corporation) and two were judged unacceptable (Energy Absorption Hexfoam Model and Renco).

Moisture Testing

The three TMA's that were judged acceptable in the vibration test were next subjected to a standard moisture test. Of the three TMA's that were tested for moisture retention, only one was judged acceptable (Energy Absorption Alpha).

TTI's moisture test facility consists of a water-filled reservoir (12 ft. wide by 12 ft. long by 12 in. high) surrounded by clear plastic curtains. A steel "bed" or platform standing in the reservoir was used to support the TMA cushion being tested in a horizontal position, approximately 17 in. above ground level. The water in the reservoir is recirculated through 8 nozzles (2 on each side of the reservoir) plumbed in series at a rate of flow to simulate a 6 in. per hour rain. The nozzles are positioned 64 inches above ground level (approximately 2 ft. above the top of the TMA being tested) and oriented to deliver cone-shaped sprays covering the top and sides of the test cushion.

In the moisture test, the TMA cushion is first weighed. Then it is placed on the "bed" (i.e., the support structure) inside the test chamber and sprayed with water non-stop for 24 hours. At the end of 24 hours, the spray is turned off and the TMA is allowed to drain for one hour. The TMA is then reweighed. The weight gain recorded for the TMA serves to define "moisture retention." The criterion for an acceptable weight gain during this test was set at 5 percent of the initial weight of the cushion.

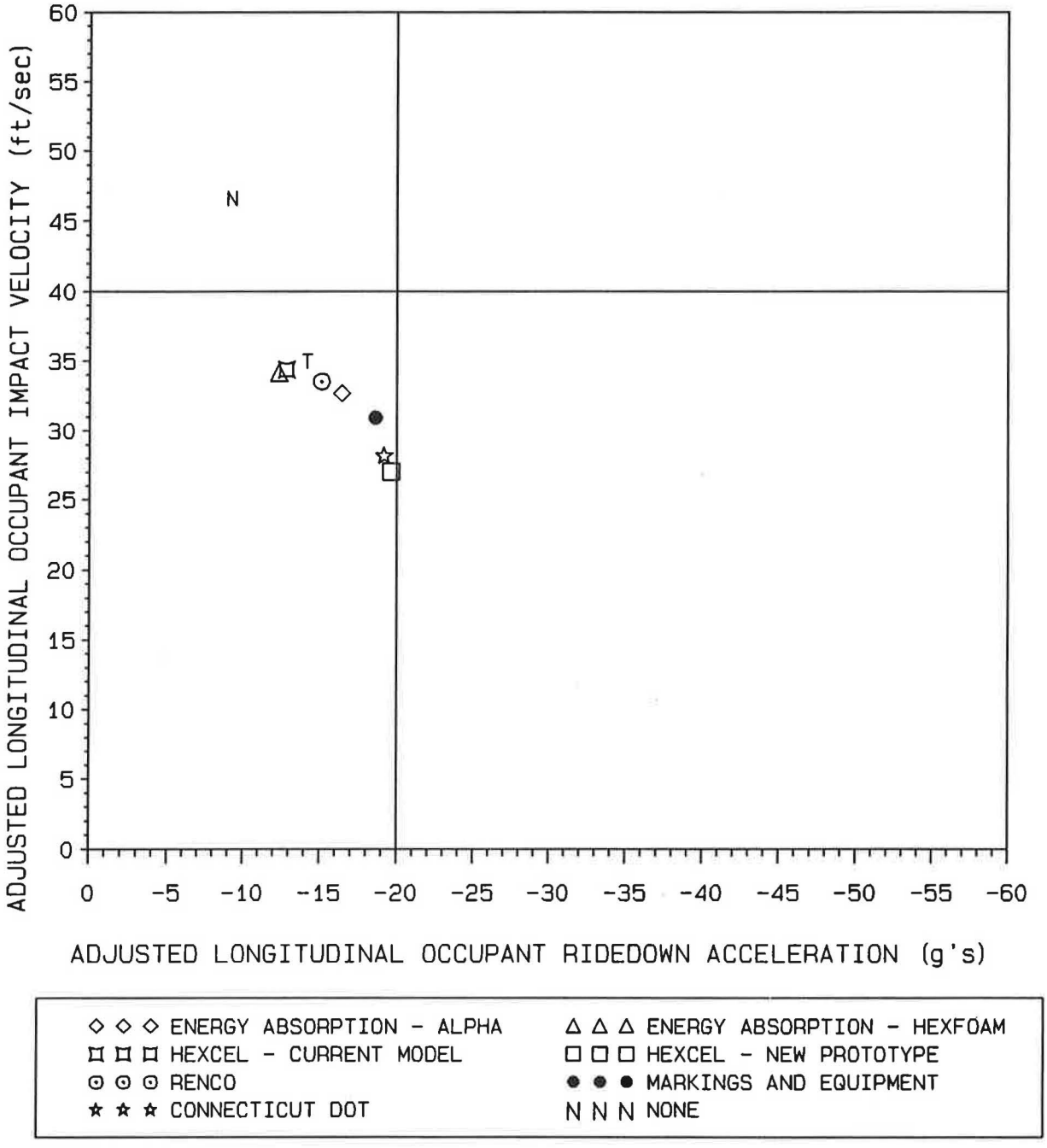
PROPOSED TMA PERFORMANCE SPECIFICATIONS

Based upon the work done during this study, future performance standards for TMA's were proposed in three areas: crash testing, vibration testing and moisture testing.

Crash Testing

A minimum of two crash tests were proposed for qualifying TMA's for purchase by TxDOT in the future:

- Test 1: An eccentric (off-center) test with a 4,500-lb pickup truck or utility vehicle traveling at 45 mph. The centerline of the impacting vehicle would be aligned with a point half way between the centerline of the TMA and the left (or right) side of the TMA.



(Data point "T" from Test Series 4 is provided for comparison)

Figure 1 Adjusted Occupant Impact Velocity and Ridedown Acceleration by TMA Make/Model Test Series 1, (Griffin 1991).

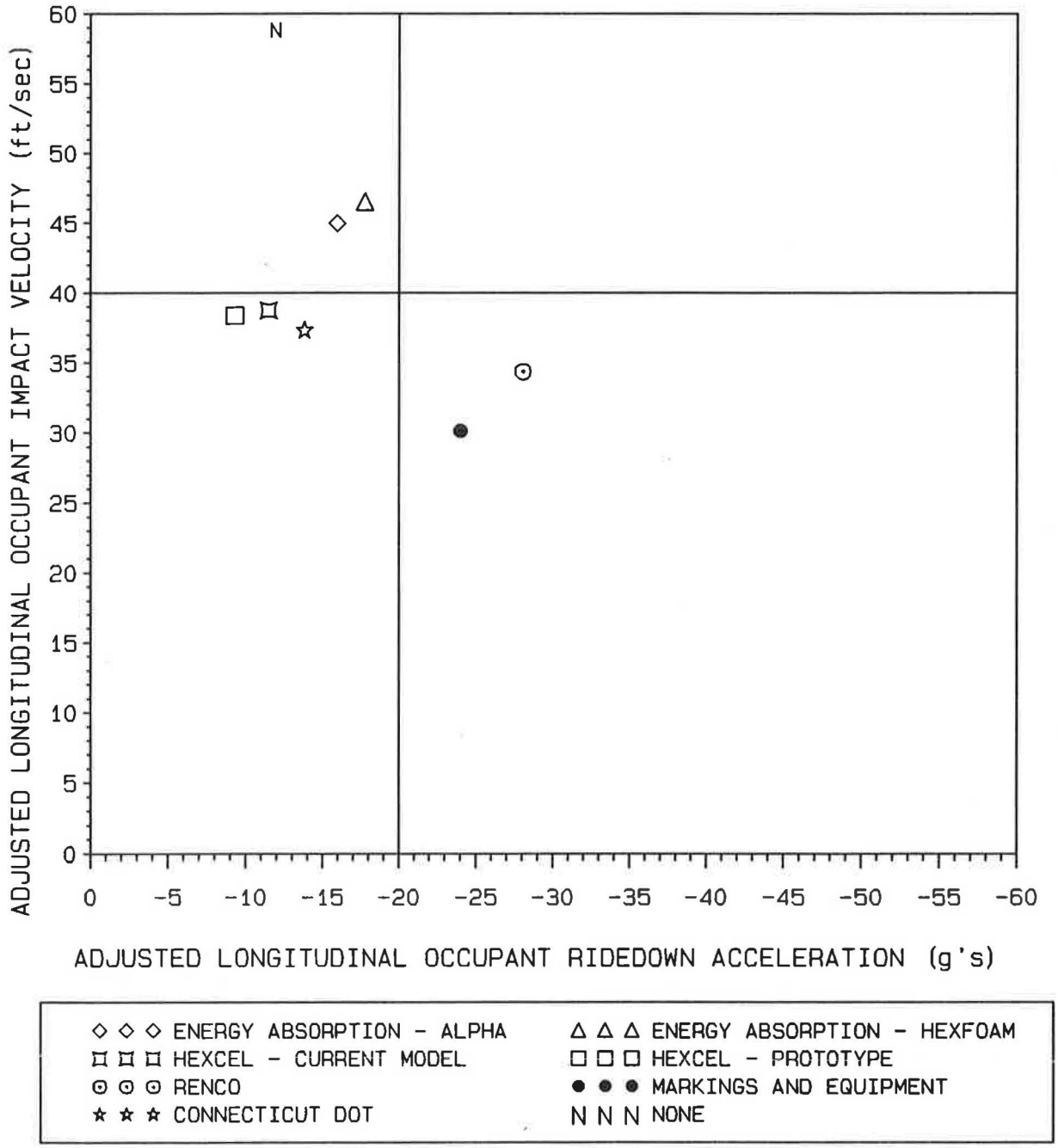


Figure 2 Adjusted Occupant Impact Velocity and Ridedown Acceleration by TMA Make/Model Test Series 2, (Griffin 1991).

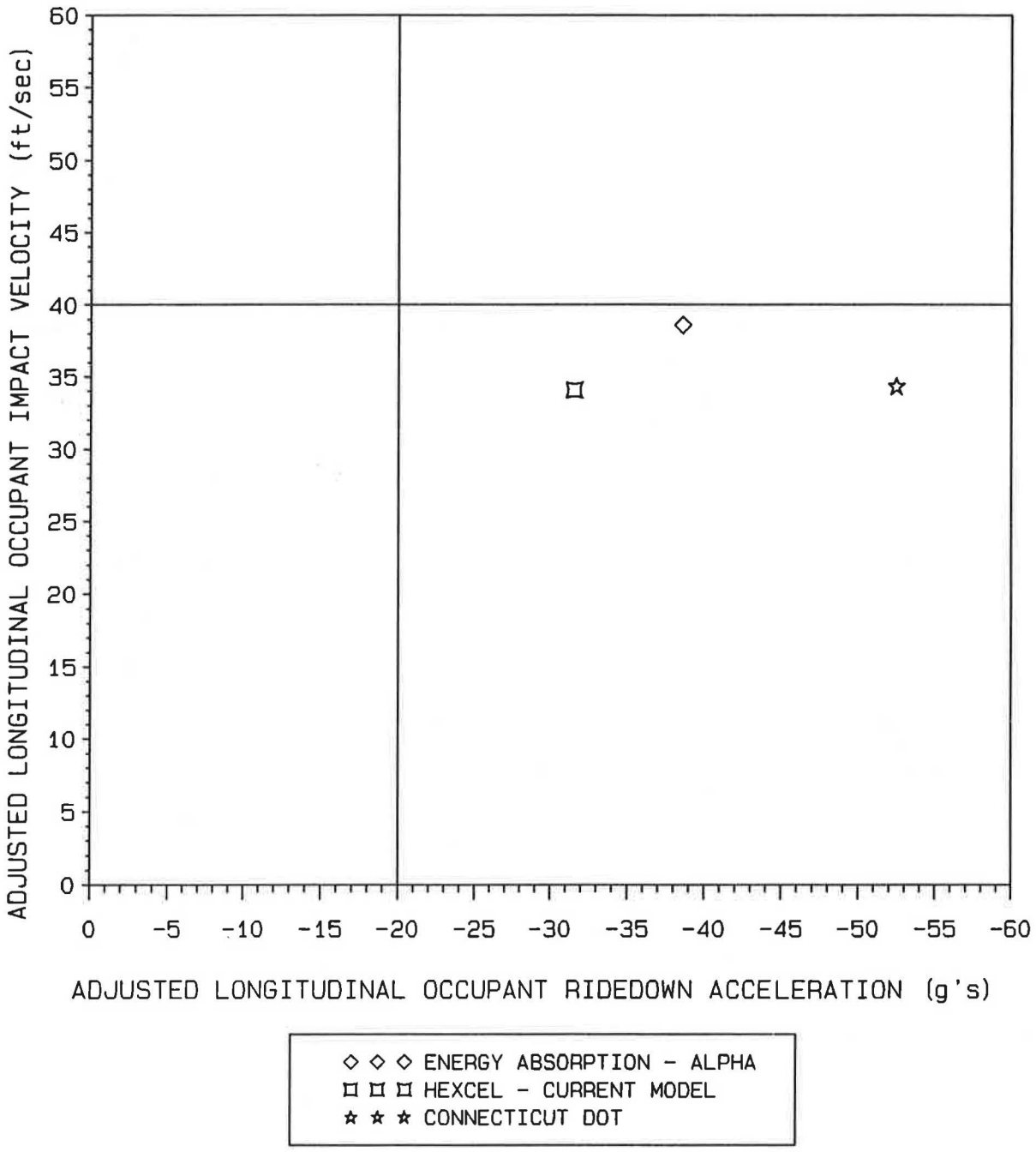


Figure 3 Adjusted Occupant Impact Velocity and Ridedown Acceleration by TMA Make/Model Test Series 3, (Griffin 1991).

- Test 2: A head-on (centerline-to-centerline) test with an 1,800-lb passenger car traveling at 45 mph.

Test Conditions: In both tests the dump truck should be ballasted to 14,000 lbs before the TMA is attached. The parking brake on the truck should be set and the transmission put in second gear. In addition, the rear wheels on the truck should be prevented from rotating by chaining, or through other means.

In all other respects, both tests should be conducted in accordance with *NCHRP Report 230*.

Acceptance Criteria: Occupant impact velocities and occupant ridedown accelerations in both tests should be within stated quantitative limits as proposed in *NCHRP Report 230*. Other applicable qualitative evaluation criteria cited in *NCHRP Report 230* also should be met.

There is a tendency in the crash test literature to emphasize the quantitative evaluation criteria in *NCHRP Report 230* and to give short shrift to the qualitative criteria when assessing TMA's, and other test articles. From the experience gained in this study, and based on the test reports contained in the literature, it appears that particular attention should be paid to vehicle underride and occupant compartment intrusion in future evaluations of TMA's.

Vibration Testing

The vibration test apparatus, procedures and performance criteria developed during this study appear to provide a reasonable test of how well a TMA will "hold up" in real world operations.

Test Conditions: The cushion portion of a typical TMA is attached to a vertical plate. The plate is then sinusoidally oscillated up and down at 7 Hz through a displacement of 0.6 in (peak to peak). The test is continued for 40 hours, 8 to 10 hours per day over a 4 to 5 day period.

Acceptance Criteria: Quantitatively, a cushion will be judged acceptable if it sags no more than 0.5 in. at the left and right rear corners of the cushion after 40 hours of vibration. Qualitatively, any damage sustained by the unit during testing (e.g., popped rivets, cracks, distortions in sheet metal, etc.) should be minor. If any damage sustained might reasonably be expected to reduce the energy absorbing characteristics of the cushion, the cushion is unacceptable.

Moisture Testing

Test Conditions: The cushion portion of a TMA is placed on a frame inside a 12-ft. by 12-ft. moisture chamber. The cushion is oriented in the normal, horizontal operational position. Through eight nozzles positioned approximately two feet above the cushion, water is sprayed onto the top and sides of the unit at a rate determined to simulate a 6 in. per hour rain. Spraying is continued non-stop for 24 hours.

Acceptance Criteria: The TMA cushion is weighed before it is placed in the moisture chamber and one hour after it is removed from the chamber. If the weight of the unit is increased by more than five percent, this test is unacceptable.

RECOMMENDATIONS

Three recommendations were offered to the TxDOT based upon the work carried out during the course of this study:

- As an interim measure, accept three (3) truck mounted attenuators for purchase by the TxDOT:
  - Energy Absorption Alpha Model TMA
  - Hexcel TMA (current model offered for sale)
  - Connecticut DOT TMA

- In the relatively near future (say, two or three years hence), require all manufacturers who would sell TMA's to the TxDOT (including the three named above) to pass the crash, vibration and moisture tests defined in the previous section. Between now and the time the new purchase requirements go into effect, a TMA would be deemed acceptable for purchase by TxDOT if it was found to pass the new performance requirements (defined in the previous section) or the performance requirements met by the three (3) makes and models of TMA's (named above) during this study.
- TxDOT should serve notice to the industry that TMA's currently manufactured for sale in this country can be significantly improved, and that in the not too distant future (say, within the next four years), it (the Department) intends to be purchasing such TMA's. Realistically, and within the next four years, TxDOT should expect to be able to purchase TMA's that adequately protect occupants of 3,500-lb vehicles striking TMA's at 55 mile per hour.

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EUROPEAN EQUIPMENT RESEARCH

Brian E. Cox, *Strategic Highway Research Program*

INTRODUCTION

This paper is based upon a survey of innovative equipment for road construction and maintenance recently completed by the Transport Research Laboratory for the United Kingdom Department of Transport. At the time this paper was written, the analysis of survey results was not complete and thus this paper is based upon the preliminary findings.

The final survey results will be published in a six volume report, but in the meantime it is hoped that the following excerpted descriptions of equipment, related to their road maintenance and construction applications, will be of interest.

CHIP SEAL

More attention is being paid to design details, in particular to binder spray mechanisms. In addition, greater use is being made of computer controlled systems for rate of spread, temperature and pressure control. Chipping spreader developments are concentrating on application rate and the use of variable width spreader heads. For rolling chippings, vibratory rollers are gaining greater prominence and are considered to improve the orientation of the chippings in the binder film. Innovative machines designed to apply chip seals in one operation are considered the way forward. In France, where the treatment is used extensively, several prototype machines have been commissioned. One such machine, 16.5m (approx 54 ft.) in length and weighing over 40 metric tons (greater than 44 U.S. tons), has been designed to improve the placement of chip seals by allowing simultaneous spreading of the binder and the application of pre-dried chippings. Trials with this machine commenced February 1991 and observations have led to further refinements to improve performance. To date, more than one million square meters (greater than 1,200,000 sq. yds.) have been successfully applied in France with this machine.

A U.K. firm previously developed and marketed polymer modified binders for road construction and maintenance, is now marketing a surface treatment process. The equipment for applying the binder comprises a tanker of 19,000 liter capacity (5,020 gal.), with two computer controlled telescopic spraybars that give accurate distribution over widths of 0.3 to 6.0 m (1 to 19.7 ft.). However chippings are applied by self propelled chipping spreaders in a conventional way and rolled with a vibratory rubber-tired roller. Suction sweepers complete the process.

RESURFACING

What is claimed to be the first 'all-in-one' road resurfacing machine has been developed in France and is said to be ideal for smaller resurfacing and remedial road repairs. It dispenses hot asphalt binder by computer control from a 3,500 liter (925 gal.) heated tank. After application of the binder, aggregate is spread onto the road from the same vehicle using a small hydraulic crane incorporated into the bodywork of the vehicle. Material is transferred into a seven cubic meter (8.4 sq. yds.) tipping body with chip-spreading gate. Beneath the rear of the truck, a rubber-tired roller/compactor completes the process, which requires only two operators.

A computerized paving system, claimed to save material, increase machine life and ensure constant levels, has been developed by a Swedish company. The prototype comprises an on-board computer working with a laser receiver mounted on top of the machine. A transmitter at a fixed height sends a signal to the paver. This enables the computer to determine its own height and thereby regulate the thickness of bituminous material being laid. Its advantage over similar computer-controlled systems is its ability to optimize performance while maintaining the asphalt mixture layer thickness, particularly when negotiating changes in grade. The system also enables automatic logging of material usage, temperatures and laying times.

It is understood that the concept of using one machine to spread binder and the mixture has also been applied to other forms of surface treatments, such as polymer modified thin overlays.

CRACK FILLERS AND PATCHERS

The TRL report indicates that most of the innovations have originated from the United States and Canada. This may be due to differences in maintenance practices.

Personal observation indicates that preventive maintenance treatments, notably chipseals, are used much more extensively in Europe than in the United States. However, an innovative approach developed in France is an integral patching machine. This applies binder and chippings simultaneously and has rubber-tired wheels to provide initial rolling compaction. It is reported that around 200 of these machines are in use in France.

BITUMINOUS BATCH PLANT

A German company has produced a small mobile batching plant that can provide small quantities of bituminous material. Various mixes can be produced in successive batches. This gives the advantage of a high quality product at the right temperature in the correct quantity and is useful for small-scale applications.

COMBINED PAVING-COMPACTION MACHINE

A German company has developed a range of combined paving-compaction machines capable of laying and compacting bituminous material up to 300mm (11.8 in.) thick in a single lift. This is achieved using a newly developed high-power compaction system to provide a two-part screen comprising a conventional tamper and vibratory smoothing screen. The vibratory screen is a novel unit for high-power compaction, consisting of two pressure bars and an additional vibratory screen. It is claimed that the machine produces a good density and uniform compaction with optimum surface evenness for both thin and thick courses, including the use of stiff, deformation-resistant materials. Pre-compaction and final compaction are carried out simultaneously and the comparatively high temperatures required for such material facilitate these processes. It is claimed that the paving season may therefore be extended, even for rapidly cooling thin surfaces. The new system has been subjected to numerous trials both in Germany and elsewhere with some success.

It may be that the adoption of the SHRP Asphalt Mixture specification and the possible adoption of Stone Mastic Asphalt (SMA) may create a need for improved paving equipment in the United States.

CONCLUSION

Innovative equipment development in Europe would appear to be primarily directed at preventive maintenance and rehabilitation. This is doubtless due to the differences in practice between the United States and Europe. In Europe, preventive maintenance treatments, notably chip-seals, are not only used extensively, but are designed. The design procedure will typically consider traffic weight and volume, road surface hardness, skid resistance requirements, weather conditions, aggregate type and size, binder type and the rate of spread of binder and chippings. The refinement of design procedures has created a demand for equipment that can precisely deliver and vary the delivery of binder and chippings across the width of application.

Similarly, developments in surfacing material, such as SMA and other comparatively thin wearing courses has spurred a demand for improvements in paving equipment.

SECTION III ENVIRONMENTAL ISSUES

ALTERNATIVE FUELS - LEGISLATIVE MANDATES, INITIATIVES AND ISSUES

Thomas H. Maze, *Iowa Transportation and Midwest Transportation Centers at Iowa State University*

The purpose of this paper is to first examine the motivation for requiring state fleets to operate alternatively fueled vehicles. This is a public policy that is increasing in popularity and state fleets are a logic test bed for the promotion of social objectives. Next, the paper looks at the status of state alternatively fueled fleet programs.

PUBLIC POLICY JUSTIFICATION

The ownership and operation of alternatively fueled vehicles is generally more expensive than that of conventionally fueled vehicles. The equipment is more expensive, the fuels are sometimes more expensive on BTU per dollar basis, and all alternative fuels have special fuel supply/delivery problems.(*1*)

The prices of petroleum products have reached an all time low and there seems to be little reason to believe the supply of non-renewable petroleum based hydrocarbons will be consumed within at least the next several generations. For example, the retail price of a gallon of gasoline was about 1.25 dollars in 1978 (in 1990 dollars), rose to a 1.90 dollars in 1982, and has declined about one dollar in 1992.(*2*) The world demand for petroleum is about 22 billion barrels per year(*3*) and over 900 billion barrels of conventional oil reserves are remaining.(*4*) Known petroleum in tar sands and oil shale include another 5,000 billion barrels.(*5*) Hence, there are many decades of petroleum remaining for use at current consumption rates. Given that petroleum is inexpensive and plentiful, what then are the reasons for the use of public fleets as alternative fueled vehicle test beds?

There are three primary reasons why the promotion of alternative fuels should be a social objective and promoted through public policy. They are to:

- Reduce the volume local air pollution originating from mobile sources. Local air pollution, in the form of carbon monoxide, nitrogen oxides, volatile organic compounds and other harmful emissions are created by motor vehicles. For example, in the United States motor vehicles contribute 45% of the hydrocarbon emissions and 85% of the carbon monoxide emissions in a typical urban area.(*6*) There is still much debate over the magnitude of the benefits of some alternative fuels in reducing harmful emissions and some argue that particular alternative fuels may even be inferior to reformulated gasoline.

- Reduce the amount of green house gases originating from mobile sources. Between 25 to 40% of the carbon dioxide equivalent greenhouse gasses originate from mobile sources. Alcohol fuels from biomass are estimated to reduce motor vehicle greenhouse gas emissions by 70% in comparison to conventional fuels. Electricity also will reduce greenhouse gas emissions from roughly 25%, if the electricity is derived from conventional sources, to 100% if electricity is derived from solar energy.(*7*)

- Reduce the imbalance of trade payments with major oil exporting countries. Roughly 40% of the United States trade deficit is related to oil imports.(*8*) Clearly, petroleum imports have a significant impact on the United States' balance of payments.

All three of these reasons for promotion of alternative fuels represent social or national interests in the reduction of petroleum consumption. Presently, the cost of operating motor vehicles using petroleum motor fuels is generally less expensive than alternative fuels. Therefore, as long as the cost to own and operate an alternatively fueled vehicle is greater than a conventional fueled vehicle, individuals and firms cannot be expected to assume the added costs of experimentation with alternative fuels. The promotion of alternative fuels is a social objective and hence it is appropriate public policy to foster alternative fuel use through public fleets.

In addition to having the added responsibility of promoting social objectives, public agencies with large fleets have much more leverage over which vehicles are introduced into the market place. There is a great deal of cost lumpiness in changes to the manufacturing of motor vehicles and changes in the supply of motor fuel. This is due to the high level of fixed costs associated with the manufacturing and distribution of new products. Specifically, transportation equipment must be made in great numbers to bring down the average cost of the vehicle plants, processing, and vehicle distribution systems. On the fuel supply side, there is lumpiness in the cost of manufacturing fuel, the provision of fueling systems, and in the creation of fuel distribution systems. After all, the petroleum industry has had the last 100

years to build up to a distribution system that delivers 110 billion gallons of gasoline and 20 billion gallons of diesel fuel per year.(*9*)

The fixed costs of ramping up to the production quantities for engines and the building of a network for fuel delivering are likely to be significant cost barriers associated with establishing an alternatively fueled vehicle industry. Many of the start-up costs can be more easily absorbed by public agencies, who can use their market leverage through large fleet purchases of alternatively fueled vehicles.

CURRENT ALTERNATIVELY FUELED VEHICLE STATE INITIATIVES

Several states have taken a leadership role in promoting the alternatively fueled engines through state mandated purchase of or conversion to alternatively fueled engines in state vehicles. The status of each state with respect to use of alternative fuels in state owned and operated fleets is presented in Table 1. The responses in Table 1 were gathered from a questionnaire letter asking the state energy office, in each state, if they had a voluntary or mandatory alternatively fueled vehicle program for state owned vehicles. Alternative fuels were defined as liquified petroleum gas, liquified or compressed natural gas, ethanol or methanal at the 85 percent concentration or higher, and electricity. Reformulated gasoline and gasohol were not considered alternative fuels.

Six states have mandatory alternatively fueled vehicle requirements for procurement of new vehicles. They include California, Colorado, Iowa, Missouri, New Mexico, and Texas. Other states have laws requiring the purchase of vehicle that can burn "clean fuels." Some states have left the interpretation of the meaning of clean fuel to administrative rule making, and others have adopted the clean fuel definition of the 1990 Clean Air Act Amendment. Massachusetts has a demonstration program that is so large in magnitude and involves several state agencies, that it is similar to a mandatory requirement of alternatively fueled vehicles. Several states have enacted laws that are pro-alternative fuel use and require demonstrations or evaluations of alternatively fueled vehicles. However, a significant minority of states (roughly fifteen) have no alternative fuels program and do not anticipate implementing a state alternative fuels program.

CONCLUSIONS

Mandatory purchase of alternatively fueled vehicles by state fleets is a legitimate public policy for promoting a social objective. Government should use its leverage to push the market to provide alternative fuels and alternatively fueled motor vehicles. However, promoting social objectives through public programs is likely to reduce the resources available for other programs. Thus, if public agencies must partially absorb the start-up costs of making alternatively fueled vehicles commercially available and increasing the supply and distribution of alternative fuels, then fewer resources will be available to achieve other agency missions.

Several states have taken the initiative to demonstrate alternatively fueled vehicles through their state fleets. It appears that states are advancing agendas which include alternatively fueled vehicle requirements for state fleets. A recent (Spring, 1992) survey of state legislatures found that clean fuel and alternative fuel issues were on the agendas of 33 state legislatures.(*10*) Through the results presented in this paper, it is clear that more states are very likely to adopt alternatively fueled vehicle requirements to help achieve environmental and national security social objective.

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Table I Status of State Vehicle Alternative Fuel Programs

Alabama. No alternatively fueled vehicle requirements. CNG demonstration program with the University of Alabama and state fleet.

Alaska. No alternatively fueled vehicle requirements. Small demonstration program in Fairbanks. No plans for the future.

Arizona. No alternatively fueled vehicle requirements. Evaluating alternative fueled vehicles for potential use.

Arkansas. No alternatively fueled vehicle requirements. Legislation will be considering requirements in next year's session.

California. State law enacted in 1989 requires that at least 25% of all newly acquired state vehicles have clean-fuel capabilities.

Colorado. State legislature established goals for alternative fueled state vehicles, 10% of state purchased or leased new vehicles during fiscal year 1991-92, 20% in 1992-93, 30% in 1993-94, and 40% in 1994-95. Alternative fueled vehicle must be powered by CNG, E-85, M-85, LPG, and electricity.

Connecticut. No alternatively fueled vehicle requirements. Currently member of coalition of northeastern governors exploring alternative fuel options.

Delaware. No alternatively fueled vehicle requirements. Small demonstration program.

Florida. No alternatively fueled vehicle requirements. Several demonstrations. Executive order requiring state agencies to plan for the use of alternatively fueled vehicles in fleet operation in non-attainment areas. Legislation requiring use of alternative fueled vehicles in all state fleet vehicles is under consideration.

Georgia. No alternatively fueled vehicle requirements. Some demonstrations.

Hawaii. No alternatively fueled vehicle requirements. Evaluating the use of alternative fuels.

Idaho. No alternatively fueled vehicle requirements. Evaluating the use of alternative fuels.

Illinois. No alternatively fueled vehicle requirements. Legislation for mandatory purchase of alternatively fueled state fleet vehicles is being considered.

Indiana. No alternatively fueled vehicle requirements. Several state demonstrations and legislature is considering the issue of alternative fuel use.

Iowa. State law requires beginning July 1, 1992 that 5% of the new vehicles purchased by state agencies are alternatively fueled or flexible fueled and 10% beginning July 1, 1994.

Kansas. No alternatively fueled vehicle requirements. Some demonstration programs.

Kentucky. No alternatively fueled vehicle requirements. Some demonstration programs.

Louisiana. State law requires that 30% of the state vehicles are alternatively fueled by September 1, 1994, 50% by September 1, 1996. However, the definition of alternative fuel includes all fuels meeting CAA clean fuel standards (e.g., reformulated gasoline and clean diesel). Has studied options and is considering incentives for conversion to CNG.

Maine. No alternatively fueled vehicle requirements. No plans for a program in the future.

Maryland. No alternatively fueled vehicle requirements. No plans for a program in the future.

Massachusetts. In the process of demonstrating alternatively fueled vehicles with an 8,400 vehicle fleet distributed throughout four state agencies.

Michigan. No alternatively fueled vehicle requirements. Plans are in embryonic stages.

Minnesota. No alternatively fueled vehicle requirements. No plans for a program in the future.

Mississippi. No alternatively fueled vehicle requirements. No plans for a program in the future.

Missouri. State law requires both an increased fuel economy and the mandatory use of alternatively fueled vehicles. It requires that 10% of the fleets of all state agencies be alternatively fueled by July 1, 1996, 30% by July 1, 1998, and 50% by July 1, 2000.

(continued on next page)

Table I Status of State Vehicle Alternative Fuel Programs (Cont.)

Montana. No alternatively fueled vehicle requirements. Currently evaluating options.

Nebraska. No alternatively fueled vehicle requirements. No plans for a program in the future.

Nevada. No alternatively fueled vehicle requirements. No plans for a program in the future. Small demonstration program.

New Hampshire. No alternatively fueled vehicle requirements. No plans for a program in the future.

New Jersey. No alternatively fueled vehicle requirements. No plans for a program but expect state level action.

New Mexico. State law mandates the use of alternatively fueled vehicles. It requires that the state fleet shall "convert" 30% of newly purchased vehicles to alternative fuel by mid-1993 and 60% by mid-1994.

New York. Demonstration program but no alternatively fueled vehicle requirement. Legislature is presently considering a bill to ramp-up to all new vehicles being alternatively fueled by 2002.

North Carolina. No alternatively fueled vehicle requirements. Currently evaluating options.

North Dakota. No alternatively fueled vehicle requirements. No plans for a program in the future.

Ohio. No alternatively fueled vehicle requirements. No plans for a program in the future.

Oklahoma. No alternatively fueled vehicle requirements. Extensive voluntary program features zero interest loans for governmental vehicle conversions and fueling facility construction.

Oregon. No alternatively fueled vehicle requirements. Voluntary program and demonstration program.

Pennsylvania. No alternatively fueled vehicle requirements. Voluntary program and demonstration program.

Rhode Island. No alternatively fueled vehicle requirements. Voluntary program and small demonstration program.

South Carolina. No alternatively fueled vehicle requirements. Expected to evaluate alternative fuel options.

South Dakota. No alternatively fueled vehicle requirements. A small demonstration program.

Tennessee. No alternatively fueled vehicles requirements. No plans for a program in the future.

Texas. State law requires that beginning September 1, 1991 state agencies may purchase or lease motor vehicles which are capable of using alternative fuels, by September 1, 1994 30% of the fleet must be alternatively fueled and by September 1, 1996, 50% and by September 1, 1998, 90%.

Utah. No alternatively fueled vehicle requirements. A small demonstration program.

Vermont. No alternatively fueled vehicle requirements. Expected to evaluate options.

Virginia. No alternatively fueled vehicle requirements. A large demonstration program.

Washington. State law requires that starting in 1993, 30% of all state vehicles purchased must be clean fueled. State is currently evaluating the definition of clean fueled.

West Virginia. No alternatively fueled vehicle requirements. A large demonstration and evaluation program.

Wisconsin. No alternatively fueled vehicle requirements. A large demonstration and evaluation program.

Wyoming. No alternatively fueled vehicle requirements. No plans for a program in the future.

TEXAS' AGGRESSIVE ALTERNATIVE FUELS PROGRAM

Don Lewis, *Texas Department of Transportation*

ABSTRACT

Recent passage of Texas Clean Air Legislation has caused a furor of activity to be generated in the Texas Department of Transportation. Passage of Texas Senate Bill 740 requires the use of Compressed Natural Gas (CNG) or alternative fuels in 90% of the State Agencies' fleet by 1998. To undertake such a task, the Alternate Fuels Group has been established within the Division of Equipment and Procurement to assist in the development and implementation of an alternate fuel strategy for the Department.

TEXAS NATURAL GAS THE REAL BASIS FOR THE LAW

Texas produced 5.5 trillion cubic feet of natural gas in 1991 which amounted to 25% of total US production. In addition, Texas has 38 trillion cubic feet of proven reserves. With this abundant natural resource as an incentive, Texas passed Clean Air Legislation in 1989 which mandated the use of natural gas or alternative fuel in motor vehicles. As an example, one trillion cubic feet of natural gas will provide fuel for one year for approximately 8 million vehicles. The intent of the State Legislature, in passing this law, was threefold: clean up the air, develop a market for Texas natural gas and, in doing so, stimulate the Texas economy. By promoting a Texas resource that benefits both the economy and the environment, Texas hopes to become a leader in the use of alternative fuels.

TEXAS CLEAN AIR LEGISLATION SENATE BILL 740

Texas Senate Bill 740 mandates the use of alternative fuels. It requires certain entities to purchase alternative fuel vehicles and increases over time the percentage of their fleet that must be capable of using alternative fuels. Effective September 1, 1991, these organizations must purchase or lease new vehicles capable of using these alternative fuels. In addition, by September 1, 1994, the fleet description must consist of 30% or more alternative fuel vehicles. This percentage increases to 50% in two years and to 90% after four years.

The Texas Air Control board has defined which fuels qualify as an alternative fuel. Currently these include natural gas, liquefied petroleum gas, methanol and electricity. The 1998 deadline applies only if the Texas Air Control Board determines that the program has been effective in reducing area total annual emissions.

TEXAS

To appreciate better the impact of Senate Bill 740 upon the Department, I would have to begin by describing just how big Texas is. The second largest state in the union is called home by over 16 million people driving to work every day in 12 million vehicles on 293,000 miles of highway. Texans are truly a mobile lot. We will need a large refueling infrastructure to make alternative fuels work. Having 262,000 square miles demands frequent refueling stations.

TxDOT RESPONSIBILITY

With an annual budget of $2.7 billion dollars, the Department's 15,000 employees are responsible for maintaining 182,000 miles of highway. This is the largest amount of pavement mileage in the United States. The Department has subdivided the state into 24 districts consisting of 430 on-site refueling locations.

IMPACT UPON TxDOT

The impact of Senate Bill 740 upon the Department is tremendous. The Department's fleet is the nations' sixth largest government fleet comprising more than 18,000 vehicles with a replacement value of over $400 million. Within these 18,000 vehicles, 8,800 meet the definition of a motor vehicle as drawn by the law. To meet the 90% criterion by 1998 this Department will either convert to or purchase nearly 8,000 alternative fueled vehicles. The magnitude of this task is apparent when one realizes that this law requires the Department to convert more than 30 existing vehicles per month through 1998, in addition to purchasing nearly 5,000 new alternative fueled vehicles during the same period.

IMPLEMENTATION PLAN

An ordered approach to implementing Senate Bill 740 has been undertaken by the Department. The process has been divided into five steps:

1. Monitor Federal Clean Air Legislation continuously,
2. Gain as much first hand experience within the Department as possible,

3. Develop sound procurement specifications,
4. Analyze Department fuel needs and availability of alternative fuels in each location, and
5. Choose the appropriate alternative fuel for each location.

FEDERAL CLEAN AIR ACT

We have tried to make ourselves aware of existing Federal and State Clean Air requirements. As new regulations are constantly passed into law, it is imperative that all levels of government be monitored on a continuous basis. The Federal Clean Air Act Amendments of 1990 affect major metropolitan areas of our state and we must prepare ourselves for the regulations that are forthcoming.

The Clean Air Act Amendments describe three major non-attainment areas in Texas: Houston/ Brazoria/Galveston, Beaumont/Port Arthur and El Paso. Targeted for concern with effect upon alternative fuel considerations are the ozone/carbon monoxide classifications in non-attainment counties. Clean alternative fueled vehicles may be required in these areas. Although the dates set forth in the Clean Air Act Amendments for achievement of the required percentage of alternative fuel vehicles are much later than those stated in Texas Senate Bill 740, we will continue to monitor this requirement. Other areas of concern include the requirements for the use of oxygenated fuels and the reduction of particulate matter.

EXPERIENCE FROM PILOT STUDY PROJECTS

To further our own understanding of alternative fuel technologies, a series of demonstration projects has been initiated. Twelve pickups have been converted to run on LPG, each carrying a 40 gallon fuel tank. In addition, we have converted 19 light duty pickups and five sedans to run on CNG. Each sedan carries five gallons equivalent of CNG while each pickup carries ten gallons--equivalent. A quick-fill CNG compressor station (built by Corken International, Oklahoma City) has been installed at our Austin District Office. The station consists of a 70 cfm compressor and 200 gallons- equivalent of stored compressed natural gas. A slow-fill CNG compressor, called FuelMaker, is being installed. We anticipate using a few small compressors in locations that have small quantity demands. To assist us in the conduct and analysis of these conversion projects, we are working jointly with the University of Texas at Austin, Center for Transportation Research. They are developing an evaluation framework including economical, environmental, operational and technical strategies.

DETERMINE FLEET LOGISTICS

The data gathered from our fleet management data base has been manipulated in several different ways. Location criteria established the number of vehicles assigned to each of the 430 fuel sites in the state. Mileage-perday data established mileage habits. Classification data sorted the vehicles into groups of sedans, light to medium-duty trucks and heavy-duty trucks. Engine type data established the number of vehicles powered by gasoline and diesel engines.

MAKEUP OF THE FLEET

The breakdown of these vehicles by classification shows an even distribution between light-to-medium duty trucks and heavy duty trucks, with the sedans making up only about 12% of the fleet. Gasoline fueled vehicles outnumber diesel fueled vehicles by a three-to-one margin. Most of the sedans and light to medium duty trucks are gasoline fueled.

DETERMINE FLEET FUELING OPERATIONS

Data from each of the 430 fueling locations was analyzed in detail. Types of fuel now available at each location were compiled with daily and weekly usage amounts. A delivery capacity analysis consisting of the number of pumps and associated nozzles provided an understanding of fuel delivery for each location. This data provided not only usage quantities but also a queue analysis of the pumps on a daily basis. It was very interesting to learn that on average, most vehicles travel only 50 miles per day and use only 4 gallons of fuel. On-site storage capacity for each fuel type and refill service records provided a check and balance method for determining if fuel usage agreed with fuel purchases. A survey of each location determined if natural gas was available (it was in over half the locations) and if LPG was available (it was in all locations).

INVESTIGATE IMPLEMENTATION STRATEGIES

Consideration of alternative fuels for replacement of gasoline or diesel necessitates a consideration for the required range and performance of each application. Some vehicles may require a driving range farther than that possible with CNG while others may not be able to

operate with the inherent power loss obtained when using LPG. Various fill station concepts also must be considered. Available for CNG are quick-fill and slow-fill designs that use on-site compressors, each varying considerably in cost and capability. Also available for CNG refueling applications are nurse trucks that service the fleet every night upon their return to the yard. The fuel storage and tank capacity requirements for both CNG and LPG must be accurately calculated to provide the required service at the lowest investment cost. The following points have been determined from our research:

- Most of the 430 locations in the state only have 20-30 vehicles per site.
- Most of the vehicles travel approximately 50 miles per day or less and refill with gasoline only once or twice per week.
- Our test CNG and LPG vehicles are averaging 10% less on CNG and 15-20% less on LPG.
- We believe a 10 gallon equivalent supply of CNG will be adequate for most light-duty pickup applications.
- We believe that a 5 gallon equivalent supply of CNG may be inadequate for most sedan applications.
- Due to the high cost of the stand alone CNG compressor fill stations, we believe that CNG may not be cost effective in small locations.

SPECIFICATIONS

To assure a reliable conversion, the Department has developed its own conversion specifications for gasoline fueled vehicles. These specifications require the conversion components be approved by EPA or CARB. Additional elements of the specifications include the requirement for automatic fuel switch-over valves in CNG converted vehicles. This valve automatically switches the fuel from CNG to gasoline when the CNG supply is depleted. Due to the almost instantaneous stalling that occurs when CNG is depleted, we will require this device for safety reasons. We require the original equipment air filter be kept, wherever possible. Setup on a dynamometer is also required. The dyno insures that converted engines maintain a horsepower rating of 85-100% after conversion. The Department is using Sherex type refuel probes, and we understand that this style may become an industry standard.

INITIAL FINDINGS

Our initial findings indicate that diesel conversion technology is premature. No large manufacturers are presently offering alternative fuel CNG or LPG engines in the small sizes we need and there are no approved conversion kits on the market today approved by the EPA or CARB. Life cycle cost benefit analysis for both CNG and LPG conversions show that the higher priced conversions are not cost effective for the TxDOT operation. Only when the price for alternative fueled vehicles is reduced, which we anticipate will happen with large scale production of new vehicles, will lifetime cost effectiveness be realizable. The environment will benefit from long term use of dedicated alternative fuels, but such benefit is very difficult to quantify.

STRATEGY FOR 1992

We plan to initiate the following strategies in our first effort to meet the requirements of Senate Bill 740:

- We plan to purchase 559 alternative fuel vehicles this year.
- Three-hundred and sixteen will be fueled by CNG and 243 will be fueled by LPG.
- One-hundred of the CNG vehicles will be dedicated, mono-fuel GMC Sierra 3/4 ton pick-ups.

Our assignment strategy was based primarily on the availability of natural gas in various TxDOT locations. When natural gas was available, a CNG vehicle was assigned. If natural gas was not available, then LPG was assigned. We are currently requesting waivers on all diesel engines until proven technology is available from the original equipment manufacturer.

Two-hundred and eleven of the 430 locations received new vehicles for 1992. Thirty-eight locations have access to public CNG stations, so we placed 212 vehicles at these locations. Thirty-three additional locations have natural gas on-site (but no access to public stations) so we plan to install small, slow-fill compressors that will support a total of 104 vehicles. The remaining 140 locations will receive 243 LPG fueled vehicles.

AREAS OF CONCERN

The following areas of concern should be weighed before selecting an alternative fuel:

- Inconsistency of natural gas. Delivery pipeline variances in purity and BTU content occur unlike the consistency found within gasoline and diesel fuel.
- Proven technology. Converting diesel engines to alternative fuel use has potential problems related to engine durability and acceptable operational performance.
- Refueling infrastructure. The CNG infrastructure is small in Texas. Nozzle standardization must be considered.
- Warranty. Converted vehicles should be covered by a warranty for three years.
- Steady supply of CNG in the Wintertime. Natural gas delivery has been curtailed to commercial businesses during severe cold spells within Texas.
- Fuel prices. The greatest cost benefit for using alternative fuel is the price differential between the alternative fuel and gasoline or diesel fuel. These prices fluctuate regularly, sometimes greatly. Predicting savings is risky.
- Conversion Prices. Prices vary from vendor to vendor. Competitive bidding will help keep the prices low.

CONCLUSION

Texas has become very proactive in environmental protection in the last several years and will move toward more stringent Clean Air Legislation for the future. Senate Bill 740 represents a different approach to a way of life that has been standard for many decades. The idea of alternative fuel is hindered by the ready availability of gasoline and diesel fuel. A large infrastructure for CNG is currently not in place but is growing. Many ideas and many ideals will have to change for alternative fuels to become commonplace in Texas.

CONVERSION, FLEXIBLE FUEL AND DEDICATED ENGINES: EMISSIONS, PROPERTIES, COSTS, AND DRIVING RANGE

Richard L. Bechtold, P.E., *EA Engineering, Science & Technology, Incorporated*

WHY USE ALTERNATIVE FUELS?

There are two main reasons to use alternative fuels: to reduce dependence on petroleum fuels and to reduce air pollution caused by vehicles using petroleum fuels. While these are desirable objectives, alternative fuels and alternative fuel vehicles are not widely available. Those who endeavor to use alternative fuels today face uncertainties that include evolving vehicle technologies and the availability of infrastructure to make alternative fuels available to the public. This paper briefly discusses alternative fuel vehicle technology at this stage of development and provides some insight into the effect various alternative fuel vehicles might have on fleet operations and cost.

TECHNOLOGY AND EMISSION CHARACTERISTICS

Natural Gas

There are two primary methods of storing natural gas on transportation vehicles: compressed (CNG) and liquefied (LNG). CNG technology is more developed than that of LNG, but neither represent "show-stoppers" relative to widespread use of natural gas as a transportation vehicle fuel. The natural gas engine fuel and emission systems are the same whether the natural gas is stored as CNG or LNG (LNG has some potential advantages due to its low temperature that may be exploited, but these advantages are far off into the future). Natural gas vehicle (NGV) emission characteristics include very low carbon monoxide (CO) emissions, low non-methane emissions, zero evaporative emissions, about 10% lower carbon dioxide (CO_2) emissions relative to petroleum fuels, and typically higher oxides of nitrogen (NO_x) emissions. Optimization of emission catalyst technology and development of lean-burn systems could result in significantly lower NO_x and methane emissions from NGVs.

Light duty NGVs will have a small power loss compared to use of conventional fuels, typically in the range of 5 to 10%. This is because the natural gas enters the cylinder as a gas whereas gasoline enters as a combination of liquid and vapor. This situation is reversed for converted diesel engines where power output can be increased because the air in the cylinder is used more completely compared to diesel combustion.

CNG is stored onboard the vehicle using high-pressure (2400 or 3000 psi) cylindrical tanks. CNG has about one-fifth the energy storage density of gasoline, meaning that five times the volume of CNG must be stored to provide the same driving range as gasoline. The most common cylinder material is steel, though reinforced aluminum is very popular and reinforced plastic cylinders are becoming popular for vehicle use because they weigh much less (though they cost more). Packaging of sufficient CNG cylinders on the vehicle to give the same operating range when using gasoline or diesel fuel can be very difficult, especially for passenger cars. For this reason, most CNG passenger cars are bi-fuel, i.e., they retain the conventional fuel system and add the CNG fuel system, but can only operate using one at a time. Bi-fuel vehicles tend to result in compromises in terms of performance and emissions, being optimum for neither natural gas nor the conventional fuel. CNG vehicles will be heavier than conventional fuel vehicles by a small amount to several hundred pounds.

LNG is stored in highly insulated containers to keep it below methane's boiling point of -259° F. The insulation while being very good, is not perfect, and vaporized natural gas will have to be vented periodically unless the fuel is used by the vehicle. Venting times vary by fuel tank design, and are as short as a few days or as long as 10 to 14 days. LNG has about two-thirds the energy content of gasoline, so approximately 50% more must be stored to provide equal driving range. LNG tanks are lighter than CNG tanks but more costly.

LP Gases

The vehicle fuel system technology and emission characteristics of LP Gas vehicles are very similar to natural gas vehicles. The major difference in emissions is that unburned hydrocarbons are primarily propane instead of methane. LP Gas fuel tanks are similar in size and weight as LNG tanks, but are much less costly than LNG or CNG tanks. Like natural gas, engine power is reduced slightly, and vehicles can be dedicated or bi-fuel.

Methanol

There are two primary approaches to using methanol as a fuel, one for spark ignition engines and one for compression ignition engines. For spark ignition en-

gines, 15% gasoline is added to the methanol (M85) to give it sufficient vapor pressure to allow cold starts to the same low temperatures as gasoline alone. Other than changes to address material compatibility and increase the fuel flow rate to compensate for the decreased energy content of methanol, no other engine changes are needed. Because of methanol's high octane rating, an increase in compression ratio is possible with its resultant advantages, but this modification would be for dedicated engines only. Most current methanol engines are light duty and are "flexible fuel," i.e., they are capable of using methanol, gasoline, or any blend in between in the same fuel tank (no separation is required - just add the fuel that is available). Flexible fuel vehicles (FFVs) have a sensor in the fuel line to the engine that can measure the percentage of methanol vs. gasoline being delivered to the engine, and provide compensation of spark timing and fuel injection quantity/timing correspondingly. The only drawback to FFV technology is that engine design is constrained by the need to operate on gasoline. Advanced methanol engines have demonstrated very low emissions and very high efficiency, without the need for gasoline addition. These advanced engines are many years away from production but illustrate the emissions potential for methanol as a fuel. Methanol vehicles have similar mass emissions as gasoline, but the advantage is that methanol is less reactive than gasoline hydrocarbons. The range and number of toxic emissions are reduced when using methanol, but methanol produces formaldehyde emissions instead. Advanced methanol engine emissions have the potential for reduced CO, CO_2, and NO_x emissions.

The compression ignition engines modified to use methanol are to date all converted from heavy duty diesel engines. The only commercially available engine is the Detroit Diesel Corporation (DDC) 6V-92TA engine that uses neat (100% pure) methanol as fuel (with the addition of a small amount of additive). The DDC 6V-92TA uses a combination of glow plugs and combustion system design to achieve ignition under all engine operating conditions. This engine is the cleanest heavy duty diesel engine ever certified by the Environmental Protection Agency. Diesel engines also can be readily retrofitted to use methanol as a fuel by adding an ignition improver additive and modifying the fuel injection system to be methanol compatible and to provide the necessary fuel flow rate. Methanol compression ignition engines have very low particulate emissions and can have very low NO_x emissions depending on design and calibration.

Ethanol

There are three primary methods that ethanol could be used as a transportation fuel: 1) as a blend with gasoline, typically 10% and commonly known as "Gasohol"; 2) as a component of reformulated gasoline both directly but probably more likely transformed into a compound such as Ethyl Teritary Butyl Ether (ETBE); or 3) used directly as a fuel, probably with 15% gasoline known as "E85." Ethanol by itself has a very low vapor pressure, but when blended in small amounts with gasoline, it causes the resulting blend to have a disproportionate increase in vapor pressure. For this reason, there is great interest in using fuels such as ETBE as reformulated gasoline components. The primary emission advantage of using ethanol blends is that CO emissions are reduced through the "blend-leaning" effect that is caused by the oxygen content of ethanol. The oxygen in the fuel contributes to combustion much the same as adding additional air would. Because this additional oxygen is being added through the fuel, the engine fuel and emission systems are "fooled" into operating leaner than designed, with the result being lower CO emissions and typically slightly higher NO_x emissions. The blend-leaning effect is most pronounced in older vehicles that do not have feedback control systems, however, even the newest technology vehicles typically show some reduction in CO emissions. The vehicle technology to use E85 is virtually the same as that to use M85; thus, there will be very little difficulty developing E85 vehicles. The emission characteristics of E85 vehicles are not well known, but it is expected that they will be comparable to the latest vehicles using reformulated gasoline and M85 vehicles with the exception that E85 produces acetaldehyde instead of formaldehyde when combusted.

COSTS AND RANGE

Because alternative fuel vehicle technology is evolving rapidly, it is difficult to generalize about costs. However, the following table summarizes the current situation with respect to incremental vehicle costs that can be expected. Note that these are just vehicle costs - maintenance and fuel costs are in addition. Many states are offering incentives to defray some of these incremental costs.

Type of Alternative Fuel Vehicle	Typical Incremental Cost, $
Light Duty CNG	$ 1,000 +
Medium and Heavy Duty CNG	$ 3,000[1] +
Light Duty LNG	$ 2,000 +
Medium and Heavy Duty LNG	$ 4,000 +
Light Duty LP Gas	$ 750 +
Medium and Heavy Duty LP Gas	$ 1,500 +
Methanol FFV	0 to $ 2,000[2]
Ethanol FFV	0 to $ 2,000[3]
Heavy Duty Methanol	$10,000[4] +
Heavy Duty Ethanol	$10,000[5] +

Notes:

1. Assumes conversion of existing engine. Costs for dedicated heavy duty natural gas engines not established. Some CNG transit buses cost $30,000 to $50,000 more.
2. Ford and General Motors have been charging $2,000 extra for their FFVs, but Chrysler claims that in volume production, they would not charge anything extra for FFV.
3. Assumes that ethanol FFVs would use the same technology as methanol FFVs.
4. Costs for methanol heavy duty engines not well-established and likely to come down as volume grows.
5. Same engines as for methanol heavy duty vehicles - other changes similar.

OPERATING CONCERNS

Emissions

At present, there are emission regulations only for light duty methanol vehicles and heavy duty methanol engines. EPA has draft regulations for natural gas and LP Gas vehicles and engines that should be finalized in 1993. No regulations exist for ethanol vehicles and engines. Many states have not addressed how alternative fuel vehicles should be treated in terms of Inspection/ Maintenance emission tests. This is of particular concern for converted and bi-fuel vehicles.

Range

These alternative fuels have less energy per gallon than gasoline or diesel fuel. If the vehicle is bi-fuel, it usually has the same range when operated on the conventional fuel, plus the range it travel on the alternative fuel. Dedicated alternative fuel vehicles generally have lower operating range than their conventional fuel counterparts. In general, light duty CNG vehicles will have half to two-thirds the range of their gasoline counterparts. Medium and heavy duty CNG vehicles can easily have near-equivalent range because they typically have sufficient room to place the required number of CNG cylinders. LNG and LP Gas vehicles do not have as much difficulty finding room for the number and size of fuel tanks that will give them near-equivalent range as when operating on conventional fuels. Light duty methanol FFVs have about 60% the range of the same vehicle using gasoline, unless an auxiliary fuel tank is added. Light duty ethanol FFVs should have about 75% the range of the same vehicle using gasoline, unless an auxiliary fuel tank is added. Both methanol and ethanol heavy duty vehicles can usually add sufficient fuel tank capacity to have essentially equal range as when operating using diesel fuel.

Complexity

Bi-fuel vehicles are inherently more complex because there are two fuel systems onboard. However, the fuel systems to use alternative fuels are also inherently more complex than those for gasoline or diesel fuel because of the differences in materials, operating principles, pressures, safety precautions, and fuel temperatures. Implementation of alternative fuel vehicles will require significant retraining of existing maintenance staff.

OTHER CONSIDERATIONS

This paper has concentrated on alternative fuel vehicles themselves - however, there are many other considerations when deciding whether to implement alternative fuel vehicles. These concerns include: Are alternative fuels readily available commercially, or must dedicated refueling facilities be established? What will be the delivered cost of the alternative fuel? Will there be a resale market for alternative fuel vehicles? How will alternative fuel vehicle affect my operations? It will be many years until these questions can be answered with some certainty. Until then, implementing alternative fuel vehicles will require careful planning to avoid costly mistakes.

OVERVIEW OF RECENT LIGHT DUTY ALTERNATIVE FUEL ENGINES

Todd C. Krenelka, *Battelle Memorial Institute*

ABSTRACT

Some light duty vehicles are now available for purchase that use M85, E10, propane, CNG, and reformulated gasoline. The engines for these vehicles have some special design features to accommodate the physical characteristics of these fuels. The available vehicles include sedans, pickup trucks, and vans. Several thousand such vehicles have been sold in the U.S. last year, and the outlook is good for both continued demand and continued supply of these vehicles. The costs for these vehicles are not settled, and they have some limitations on weight and range.

INTRODUCTION

The alternative fuels that are now being widely considered for use in light duty engines are M85 (a blend of 85% methanol and 15% gasoline by volume), E15 (a blend of 15% ethanol and 85% gasoline by volume), propane, compressed natural gas (CNG), electricity, and reformulated gasoline. While other fuels can be used in light duty engines, these six are the fuels for which engines are currently available by major manufacturers. Most notable by their absence from this list are M100 (pure methanol); E100 and E85 (pure ethanol and 85% ethanol in gasoline, respectively); and liquified natural gas (LNG). While these other alternative fuels are being used successfully in heavy duty applications today, none are being endorsed by the major domestic manufacturers of light duty cars and trucks at this time.

Light duty engines in the U.S. today are predominantly spark ignited, fuel injected, four cycle machines with electronic fuel and ignition control. The alternative fuels have some physical properties that must be considered and accommodated for successful use in light duty engines.

FUEL PROPERTIES

M85 has its fuel properties dominated by the alcohol fraction. It has low lubricity. Its heat content is roughly half that of gasoline for an equal volume. Its volatility, as expressed by Ried vapor pressure, is lower than gasoline. Its heat of vaporization is significantly higher than gasoline. It has a high octane rating and is somewhat corrosive.

Propane and CNG share a set of physical properties as gaseous fuels. While propane is stored in liquid form, it is introduced into the engine as a gas. Since these substances are gases at standard atmospheric conditions, they avoid all issues of atomization and vaporization. Their gaseous form also demands that the fuel charge occupy many times the volume of an equal energy charge of gasoline. This volume is significant compared to the volume of the air charge for a combustion cycle. Both of the gaseous fuels have a high octane rating compared to gasoline. Both also share a very low lubricity compared to gasoline.

Both E10 and reformulated gasoline can be considered gasoline substitutes. Almost any engine sold in the U.S. today that uses gasoline can use E10 or reformulated gasoline without any ill effect. For engine design, most of their important physical characteristics are like gasoline. E10 does have a higher volatility than gasoline as expressed by Ried vapor pressure. The 15% ethanol makes the fuel more corrosive to metals and elastomers than gasoline alone, though all major manufacturers now account for this in their selection of materials. E10 is now sold widely as gasoline, with the ethanol included as an inexpensive octane enhancer. Reformulated gasoline has a lower volatility than current unleaded gasolines. The fuel has a lower fraction of aromatics and other chemistry changes, including the substantial use of ethers to increase its oxygen content.

ENGINE REQUIREMENTS

When the properties of alternative fuels are considered for engine design, a few requirements emerge. The lower lubricity of the gaseous fuels and M85 demand that the piston rings and valves be hardened against wear. The higher volumes required for a charge of these three fuels require an increased capacity for the fuel delivery system. The electronic programming for the fuel and ignition schedules must be changed. M85 also requires corrosion resistant materials and an enhanced cold start system.

ENGINE DESIGN APPROACHES

The design approach being used for M85 engines is a "fuel flexible" design. The engine can accept any concentration of methanol in the gasoline from 0 to 85%. The valve faces and seats are hardened. The top piston ring is plated for hardness. Internal parts of the fuel pump are plated against corrosion.

None of the engines offered now take advantage of M85's high octane rating. They operate at common

gasoline compression ratios. M85 engines are universally supplied from original equipment manufacturers, with no aftermarket conversion kits widely available.

The design approaches used now for the gaseous fuels include both single fuel and bi-fuel vehicles. The bi-fuel vehicles retain their gasoline fuel tanks and can switch between the two fuels while running. The valve faces and seats are hardened, and the exhaust valves have no rotators. The cylinder heads are stress relieved to increase heat resistance. Many designs have abandoned port injection for a gas mixer in the throttle body. The gaseous fuels are available both from the original equipment manufacturer and as aftermarket conversions. Engines are available from the manufacturer with a "gaseous fuel prep kit" that includes the upgraded parts for wear and heat resistance, although the fuel system is entirely gasoline. These are intended for use with aftermarket conversions to the alternative fuel.

AVAILABLE VEHICLES

Battelle Memorial Institute has recently obtained a fleet of light duty panel vans using M85, propane, reformulated gasoline, CNG, and electricity. These vehicles are in the South Coast Alternative Fuels Demonstration project, also known as the Clean Fleet Project. The demonstration attempted to obtain full size panel vans from Chrysler, Ford, and Chevrolet that operate on these fuels. Table 1 shows that vehicles were actually available in the summer of 1992.

Table I Alternative fuel vans provided for the Clean Fleet project

Fuel	Chev. G30	Chrysler B350	Ford E250	Other	Total
Compressed Natural Gas	7	7	7	0	21
Liquefied Petroleum Gas	7	0	13	0	20
Methanol (M-85)	0	0	20	0	20
Reformulated Gasoline	7	7	7	0	21
Electric	--	--	--	4	4
Control	9	6	12	0	27
Total Vehicles	30	20	59	4	113

The vehicles began normal daily service as Federal Express package delivery trucks in southern California in the fall of 1992, and will be carefully monitored by the project for two years.

The California Energy Commission provided a list of alternative fuel light duty vehicles that are currently available in California. This is shown in Table 2.

Table II Light duty alternative fuel vehicles available for sale in California

Vehicle	Approx. Price	Fuel
Ford Taurus	$14,000	M85 FFV
Chevy Lumina	$14,000	M85 FFV
Chrysler Spirit/Acclaim	$12,000	M85 FFV
GMC Sierra Pickup	$20,000	CNG
Mercedes 300S	$70,000	M85 FFV
Chrysler RAM Van	$25,000	CNG
Volkswagen Jetta	$13,000	M85 FFV

Light duty vehicles that run on alternative fuels are now offered for sale by all three major domestic auto manufacturers as well as some imports. In general, one can obtain some sort of vehicle in any fuel, and can obtain either a sedan, pickup truck, or van. The selection is not yet broad enough, though, to choose both the vehicle type and the fuel. If a prospective purchaser is willing to consider aftermarket conversions, then propane and CNG can be used in almost any light duty vehicle.

The outlook for availability is promising. Chevrolet sold 1,200 M85 Lumina sedans in California recently. The CNG Sierra pickup was originally scheduled for a 1,000 unit production run, which quickly sold out. The run was extended to 2,000 trucks, and demand has remained strong. General Motors has recently announced that the 2,000 unit figure is an estimate rather than a limit, and all orders received will be filled.

The manufacturers are concentrating on supplying the types of sedans and trucks that are favored by fleet operators. This is in reaction to the recent legislation at Federal and State levels which target these fleets for incentives and mandates to use alternative fuels. Much has been written of the free market stalemate between supply and demand for alternative fuel vehicles and their fueling infrastructure. It appears that this impasse has been overcome by legislation, at least in part. The

regulations have created a market for which the manufacturers are now supplying vehicles.

COST, WEIGHT AND RANGE

The cost of alternative fuel vehicles has not yet stabilized. The 1992 M85 Chevrolet Lumina sedan carried a price premium of $2,000. It is not clear that the prices charged for the earliest alternative fuel vehicles are accurate reflections of the costs for developing and producing them. It may not be reasonable to expect that the manufacturers can price them accurately at this time, given the great uncertainty about the number of vehicles that might be sold in these newly emerging markets.

The weights and ranges of the vehicles are different from gasoline vehicles. M85 vehicles trade weight for range. At an equal weight as a gasoline vehicle, a M85 vehicle will have about half the range. This can be overcome by adding the weight penalty of a double size fuel tank. M85 is a liquid stored at atmospheric pressure. The tank is much like a gasoline tank, in that it can use lightweight materials and be made into odd shapes. This allows the extra M85 volume to be fit into the available space in the vehicle geometry with an odd shaped stamped steel tank.

The gaseous fuels cannot trade weight for range, but must accept some penalty in both areas. The sturdy pressurized fuel tanks are heavy compared to gasoline tanks, and must be restricted to cylindrical shapes. The packaging efficiency of round end cylinders is low compared to a stamped steel gasoline tanks made in an odd shape to fit the available space in a vehicle. The problem is less severe for propane than for CNG, because the storage pressure is lower for propane. The CNG vans provided for the Clean Fleet project have a weight penalty of between 200 and 500 kg. while simultaneously having about half the range of otherwise identical gasoline trucks. The alternative fuel vehicles have shown a slight energy consumption penalty compared to gasoline vehicles. Some portion of this is undoubtedly due to the extra weight of fuel being carried. Also, the engines provided to date don't fully exploit the high octane of the alternative fuels, and are not fully optimized for the fuels in many small design features.

ENVIRONMENTAL REGULATIONS AND ISSUES AFFECTING GARAGE WASTE

(Outline)

John Konefes, *Center for Waste Reduction at the University of Northern Iowa*

IOWA WASTE REDUCTION CENTER (IWRC)

- Established in 1988 to work with small businesses of all types in Iowa.
- Provide technical assistance with solid/hazardous wastes (HW), air emissions, and wastewater.
  - Includes information on meeting regulations and improved waste management.
  - Stress waste reduction as the best way to meet regulations.
- Although we work with all types of business, we have done a considerable amount of work with vehicle maintenance operations.
  - Conducted on-site reviews (actually visiting the facility, with a follow up report) to 230 vehicle maintenance operations.
  - Include automobile dealers, truck fleet management, farm equipment dealers, DOT maintenance garages, county garages, and municipal public works departments.

SURVEY OF STATE DOT'S

Purpose

- Determine level of knowledge and concern for garage wastes.
- Identify current waste management policies for specific wastes.

Survey

- Telephone survey of all 50 state DOTs.
- Received responses from all 50 states.

Question 1 - How many of your staff at maintenance facilities are knowledgeable on hazardous/solid waste regulations?

• 75% or more	21	42%
• 50% - 75%	5	10%
• Less than 50%	22	44%
• Not sure	2	4%

Question 2 (I) - If knowledge greater than 50%, then how did they receive this information?

• Training program	14	28%
• Video	4	8%
• Manual	9	18%
• Workshop	8	16%
• Other	5	10%

Question 2 (II) - If knowledge less than 50%, how would you plan to educate staff from your facilities on these regulations?

• Training program	12	24%
• Video	6	12%
• Manual	4	8%
• Workshop	6	12%
• No plan at this time	3	6%
• Other	2	4%

Question 3 - Do you feel that you have a need for and would utilize a training program or workshop that would enhance the knowledge of regulations for your maintenance facilities?

• Yes	47	94%
• No	3	6%

Question 4 - Rank the following items according to the level of concern at your facility. Low concern is 1 and highest concern is 5.

LOW	2	3	4	HIGH	N/A
• **Used oil**					
9--18%	14--28%	10--20%	10--20%	7--14%	------
• **Oil filters**					
10--20%	14--28%	12--24%	7--14%	7--14%	------
• **Refrigerant**					
14--28%	7--14%	10--20%	7--14%	6--12%	6--12%
• **Sludge from sumps and floor drains**					
4-- 8%	14--28%	14--28%	12--24%	6--12%	------
• **Antifreeze**					
3-- 6%	13--26%	14--28%	11-22%	8--16%	1-- 2%
• **Solvent waste**					
2-- 4%	7--14%	7--14%	19-38%	15--30%	------
• **Paint waste/filters**					
1-- 2%	5--10%	10--20%	16--32%	18-36%	------
• **Brake pads**					
10--20%	17--34%	7--14%	5--10%	8--16%	3-- 6%
• **Batteries**					
9--18%	14--28%	6--12%	11--22%	9--18%	1-- 2%
• **Used tires**					
9--18%	16--32%	5--10%	12--24%	8--16%	-------

Question 5 - What is your current waste management policy towards the following:

- Used oil filters
  - dispose in landfill 1 ..... 2%
  - drain, recycle oil, dispose filter in landfill 35 ..... 70%
  - drain, recycle both oil & filter 14 ..... 28%
- Used oil
  - burn on-site 8 ..... 16%
  - burn in vehicles 5 ..... 10%
  - recycle off-site 39 ..... 78%
  - road oiling 0 ..... 0%
  - landfill 0 ..... 0%
  - other 0 ..... 0%
- Antifreeze or refrigerants
  - temporary storage 5 ..... 10%
  - recycle on-site 4 ..... 8%
  - recycle off-site 37 ..... 77%
  - drain (antifreeze) 11 ..... 22%
  - vent (refrig) 7 ..... 14%

Question 6 - Do you have a waste reduction policy, or specific plan, in place for hazardous wastes from your vehicles or equipment?

- Yes 21 ..... 42%
- No 29 ..... 58%

REGULATORY ISSUES

Used Oil Filters

- Used oil filters used to be disposed in landfills with little consideration given to treatment prior to disposal.
- EPA has begun to implement the requirement that filters be tested to determine if they exhibited any of the hazardous waste characteristics prior to disposal. The test is the TCLP test, and filters were thought to fail for the presence of lead and/or benzene.
- EPA recently issued a final rule on the disposal of used oil filters:
  - Issued in May, effective June 19, 1992.
  - Used oil filters are exempt from the hazardous waste determination requirement if:
    - They are not made from terne-plated metal (tern is an alloy of tin and lead).
    - The oil has been removed by:
      - Puncturing the anti-drain back valve or the filter dome and hot draining, or
      - Hot-draining and crushing, or
      - Dismantling and hot-draining, or
      - Any other equivalent removal method.
    - No specs for time of draining, crushing, or other methods have been set, although EPA recommends at least 12 hours of draining.
  - Complications with the new rule:
    - No data or information on which types of filters, or manufacturers, are terne-plated.
    - Therefore, you must assume it is terne-plated and conduct the HW determination anyway, even if crushing and draining.
    - IWRC is working to try to determine which filters are terneplated.
  - Each state may have their own policy towards used oil filters, dependent in part on their regulations on used oil.

Used Oil

- EPA ruling keeps the status quo for used oil regulations nationally.
  - Not automatically a hazardous waste.
  - If disposed, then must undergo a hazardous waste determination.
  - If recycled, then exempt from regulation as a hazardous waste.
- On-site used oil burners are still allowed.
  - Used oil burned must be generated on-site, or accepted from do-it-yourself oil changers. Cannot accept from other businesses, or more stringent regs apply.
  - Combustion gases must be vented outside. Have some potential for negative impacts due to metal and organic contaminants.
- Liability for used oil mismanagement still applies.
  - $60 million Superfund cleanup in Minnesota involved used oil.
  - Large companies sued small oil generators that sent used oil to the site. Includes car dealers, service stations; county, city, and utility operations.

Refrigerant (Freon)

- Venting and recycling activities are addressed by the Clean AAA of 1990. Some states, such as Wisconsin, are also doing their own regs, in advance of the federal regs.
- First deadline was Jan 1, 1992, for larger service operations.
  - Only applies to operations that do the work "for consideration." Includes maintenance and

service of state (or county) vehicles, since the personnel are paid to work on them.
  - Service shops that work on more than 100 vehicle air conditioners in a year must have certified technicians.
  - Also must have and use refrigerant recycle equipment when working on vehicle air conditioners.
  - Only certified technicians can buy refrigerants after November 15, 1992.
- Smaller operations do not need to comply until Jan 1, 1993.
  - However, they must certify that they have serviced less than 100 vehicle ac's last year by January 1, 1992.
  - Must comply with recycling and certified technician regs by January 1, 1993.
- CFC's can be a hazardous waste, but refrigerant recycling has been exempted from the HW regs by EPA.
- The big loophole left is recharging, which is not prohibited by the CAAA.

Waste Solvent

- Sources include parts washers, carburetor cleaner, paint thinners.
- Recycle options have been covered in more detail by previous presenter.
- Important points to remember are the cutoff limits for HW regs.
  - <100 kg/mo --> CESQG 220 lb/mo, or 25-30 gallons.
  - Between 100 - 1000 kg/mo --> SQG 2200 lb/mo, or 4-5, 55 gallon drums.
  - State and Federal facilities are subject to these HW regs.
  - Summaries of the SQG and CESQG regs are available from IWRC or regional EPA offices.
- HW must be counted, even if the solvent service company says they own the solvent, and there is no storage of waste prior to pickup.
- No new changes are expected in the standard HW regs in the near future.

Antifreeze

- Common practice in the past, and in many locations now, was to consider discharge spent antifreeze "down the drain."
- Increasing concern on the part of regulatory agencies and municipal wastewater facilities for waste antifreeze.
- Regulatory status
  - Is not specifically listed as a hazardous waste.
  - May need to be tested to determine if it meets the criteria of HW. TCLP test for lead, other metals, and benzene.
  - Some state regulatory agencies require testing, or list antifreeze as a "special waste," or consider it a HW in their state.
- Test data is limited at this point, but shows that some spent antifreeze does meet the criteria of HW. One company tested 25 samples of waste antifreeze.
  - 24% failed for lead.
  - 8% failed for benzene.
- If the antifreeze is discharged to the sewer, the local wastewater authority should be notified. They may require testing, or limit the amount that can be discharged.
- If the facility is on a septic system, or a small lagoon system, then spent antifreeze should not be discharged to the sewer. Antifreeze should be collected for on-site or off-site recycle.
- Recycling - Should be done off- or on-site.
  - Off-site --> Important to determine what is being done with it, since liability for mismanagement may result for the generator.
  - On-site --> Residue from recycling may be hazardous. Should be tested for HW char. w/ TCLP

Sludge from Sumps and Floor Drains

- Typically this material is removed by a septic hauler once every few months. May be:
  - Land spread.
  - Taken to a discharge point at the WW plant.
  - Taken to the local landfill.
- All disposal options have some limitations or regulations attached to them. Often involves notification of the activity and some testing.
- Testing to determine if it meets HW characteristics is not typically done.
  - Could exceed some limits for metals, benzene.
  - Potential to be hazardous depends on what is discharged down the drain.
- Probably will be increased attention to this and some of the other wastes.
  - Testing requirements will be toughened.
  - Could be specifically listed or designated as a HW by some states.

Stormwater Permitting

- New requirements to test and get a permit for discharge of stormwater from industrial facilities.
- Applicability of requirement depends on SIC number of facility.
  - DOT SIC numbers fall outside the specified universe of affected facilities.
  - New requirement will apply only if the state elects to exceed Federal requirements.
- Construction activity that disturbs more than 5 acres will require a permit and stormwater management plan.

CONNECTICUT DOT'S APPROACH TO ENVIRONMENTAL COMPLIANCE

Kenneth Daly, *Connecticut Department of Transportation*

INTRODUCTION

If any of today's panelists were to consider the environmental impacts of a full range of organized human endeavors, he would be hard pressed to identify any enterprise having greater potential impact on our natural environment than the development and maintenance of a modern transportation system.

As society's primary means of connecting goods and services with people and opportunities, our transportation system has enjoyed continuous growth and enhancement in recognition of the positive role that transportation plays in contributing to our nation's social, economic and cultural goals. Among the greatest challenges facing transportation professionals in the 1990s, however, is the need to demonstrate that our transportation system can be developed and maintained in a manner consistent with our society's environmental values as well. This paper focuses on Connecticut's efforts to address a relatively new aspect of this environmental challenge and that is to control the environmental risks associated with hazardous wastes and other potential contaminants.

TYPES OF ENVIRONMENTAL RISK

While the risks of chemically-induced environmental impacts vary widely in scope and complexity, they can be grouped, for conceptual purposes, into two major categories. The first category pertains to project-related risks, and would include encounters with hazardous or contaminated materials in the highway right-of-way during construction activities. The second category would include operational risks that are typically associated with transportation support facilities such as airports, rail yards, and highway maintenance facilities.

The common area shared by both the major categories represents those risks that are not facility based or project related, but can be managed on a statewide basis, at a programmatic level. For example, leaded sandblast debris generated under a statewide bridge rehabilitation program might be addressed as a programmatic risk. The remainder of this paper will emphasis ConnDOT's efforts to control facility-based, operational risks.

NATURE OF ENVIRONMENTAL RISK

Within this context, the environmental risk associated with any DOT support facility will express itself through the interaction of the variables of Activities, Materials and Facilities. If the architectural characteristics of a highway maintenance facility fail to support effectively the activities carried out at that facility, or fail to control the potential contaminants used in support of such activities, then the facility itself represents a potential source of environmental contamination. Once released, contaminants will migrate from the source, along available pathways, and will eventually impact one or more sensitive receptors. While a cost effective compliance program should target a substantial share of the resources toward the control of the variables, a remedial program element, focused on the source-pathway-receptor relationship, also will be necessary where past releases have already occurred.

FUNCTIONAL APPROACH

Accordingly, ConnDOT's Division of Environmental Compliance has been organized along the functional lines. Because environmental compliance is considered an agency-wide function in Connecticut, the Division has been placed within the Office of Transportation Chief Engineer. The investigative services function is implemented under an on-call consultant agreement, under which a variety of pre-negotiated study tasks are executed on an as-needed basis. The remedial engineering elements are carried out by the consultant via pre-negotiated design and construction management tasks. In negotiating these tasks, an assumed level of effort for each type of service was used to derive a standard fee for each task when the Agreement was executed. At the time each assignment is authorized, however, an agreed upon level of effort factor is applied to each required task to accommodate more accurately actual field conditions. Compliance management efforts are largely carried out in-house with technical assistance from the Department's consultant.

COMPLIANCE PROGRAM

Based upon analytical data collected at approximately 125 ConnDOT facilities over the past several years, with continuing analysis of applicable Federal and state regulations, a comprehensive compliance program has been undertaken. The program consists of three major components. First is a source control component aimed at improving each facility's physical ability to support the

types of activities assigned to it, and to accommodate the potential contaminants employed in support of those activities. An environmental remediation program has been undertaken to improve site conditions at locations where past releases are known to have occurred. Third is a comprehensive Risk Management Program aimed at improving personnel operating practices, specially as they relate to material storage and handling, as well as waste management.

Operational Risks in Transportation

To illustrate the risks that the source control component is intended to address, consider a hypothetical high-risk maintenance facility designed and built in the 1950s. It has a salt storage structure with a capacity equal to roughly 25% of the facility's annual usage. It also has a salt/sand mix pile, which is typically covered during fair weather but must remain uncovered for loading and mixing operations during storm events. There is a fuel island served by underground steel storage tanks, which by 1990 would have surpassed their useful life, especially without cathodic protection. Also there are vehicle maintenance and repair facilities that would likely be served by floor drain systems routed directly to the soil, or perhaps to a neighboring watercourse.

Given the range of common maintenance functions and the variety of related contaminants used, it is clear that 1950s site technology is ill-suited for the highway maintenance demands of the 1990s. It also should be noted that, while many of the more toxic hydrocarbon-based contaminants can be cost-effectively removed from impacted groundwater, salt-laden groundwater is far more costly, if not impossible, to remediate.

In response to similar deficiencies identified at many of Connecticut's facilities, generic designs for salt storage sheds, fuel storage tanks and drainage improvements were developed.

Source Control Component

The risks associated with salt storage and handling operations are largely attributable to the limited capacity of the structures typically used for this purpose. An under-sized structure not only requires that salt be delivered more often, but also necessitates that delivery and mixing operations occur outside, under less than optimal weather conditions.

To offset this risk, state-of-the-art salt storage and handling systems are now being constructed in Connecticut. Each of the gambrel-styled structures features separate salt storage and mix storage areas, and a 25 foot high fabric door to facilitate delivery. The structures are sized to accommodate up to 65% of each facility's annual usage, and effectively contain delivery, storage and mixing operations within a single structure. The generic design for the 35 foot high facilities utilize laminated wooden arches that rest on concrete pilasters to support the superstructure.

The Department's aging underground fuel tanks also were found to represent a very substantial risk to the environment. Many of the tank systems were installed during the 1950s and were found in advanced stages of deterioration. Volume measurements were typically taken by periodically inserting a calibrated stick into the tank and comparing the measured fluid level to delivery and usage records. This approach generally did not detect leaks until relatively large volumes of fuel had escaped to the environment.

Under the source control component of its compliance program, ConnDOT has replaced most of the underground fuel storage tanks with new systems. These new systems not only conform to Federal and state regulatory requirements, but go one step further by incorporating computerized, temperature-corrected, level sensing systems. These units automatically transmit real-time volume measurements to the host facility on a periodic basis. While fiberglass tank systems have been installed at many ConnDOT facilities, especially sensitive locations have been fitted with cathodically protected, double-walled, steel tanks.

During earlier site investigations, it was learned that the floor drain systems serving many of ConnDOT's maintenance facilities were promoting the release of degreasing fluids, oils and vehicle detergent wastes to the environment. Further, it was found that pavement conditions at most of the facilities were generally poor. In anticipation of NPDES and TC regulations prohibiting such discharges, ConnDOT's source control program component was enhanced to include a full compliment of drainage controls under the program. Layers of impermeable, geotextile fabric are laid between courses of bituminous pavement where salt is handled. This fabric provides additional protection in the drainage area serving salt handling operations at ConnDOT's maintenance facilities.

Prior to discharge, all storm-water accumulating at ConnDOT facilities is collected and routed through a series of gross particle separators. These separators are sized to capture 90% of the sediments entrained in facility storm-waters.

Additionally, in accordance with the requirements of ConnDOT's general permit under EPA's National Pollutant Discharge Elimination Program, all floor drain

systems in non-sewered areas are being re-routed to underground holding tanks. These tanks are fitted with the same level sensing systems utilized under the Department's fuel tank replacement program. In areas served by sewers, the floor drain systems are being retro-fitted with oil/water separation units.

Site Remediation Component

Unfortunately, the site investigations conducted at ConnDOT's facilities found that soil, groundwater, and drinking water resources had been impacted by past operations. It was therefore necessary to undertake a program of remedial projects aimed at restoring environmental conditions in affected areas.

In the early stages of the remediation program, the Department relied heavily on land filling as its primary response to soil contamination, particularly at leaking underground tank sites. More recently, however, ConnDOT has been able to capitalize on a number emerging treatment technologies, such as vacuum extraction systems. This technology is particularly cost-effective in capturing volatile soil gases often encountered near fueling system failures.

The discovery of approximately one million gallons of PCB contaminated diesel fuel under the former New York/New Haven Rail yard has presented a formidable remedial challenge to the Department. To avoid interference with critical ongoing operations at this facility, ConnDOT will employ a combination of groundwater extraction and insitu bio-remediation technologies to restore subsurface conditions at this property. Genetically developed bacteria are particularly effective against PCB contamination. This project is currently approaching final design.

Since encounters with low-level hydrocarbon based soil contamination represent the most common impediment to ConnDOT's maintenance and construction activities, the Division of Environmental Compliance is seeking state regulatory approval to implement a low temperature soil treatment program. While Connecticut DEP has authorized the use of thermal units on a limited basis, ConnDOT hopes to address this ongoing risk on a more programmatic basis.

With respect to groundwater contamination, it is known that treatment technologies are more cost-effective when they can be implemented before the contaminants are permitted to migrate horizontally within the groundwater matrix and dissolve. Therefore, to reduce the time frame between the discovery of a release and the start of remediation, ConnDOT has purchased the first of six pre-packaged, mobile groundwater treatment units to be deployed throughout the state on an as-needed basis. A unit can be purchased at a cost equal to the amount it would cost to lease the required components separately for one year.

Risk Management Component

As noted earlier, the degree of environmental risk associated with a particular facility is also influenced by the operating procedures and material practices employed by facility personnel. Therefore, as an additional defense against the release of contaminants, ConnDOT has developed a comprehensive Risk Management Program component for all operational facilities.

The Risk Management Program consists of four major elements. The first is a statewide "Worker-Right-to-Know Plan," which was developed to conform with OSHA's Hazard Communication Standard, and provides basic storage, labeling, handling and safety data to all personnel working with any of the 850 OSHA regulated substances used by the Department. To conform with this important federal standard, it was necessary to develop detailed chemical inventories and provide training at all 125 ConnDOT facilities.

The second part of ConnDOT's Risk Management Program is a Hazardous Materials Management Plan, which focuses on those substances identified as 'hazardous' under the Resource Conservation and Recovery Act, the Toxic Substances Control Act, and related legislation. The plan and program manual sets forth specific procedures for the storage, handling and transport of all such materials, and describes the emergency preparedness procedures to be followed in the event of an uncontrolled release. This program element is supported also by a training program.

The Department's objective in developing its Risk Management Program is to provide 'cradle to grave' management of all regulated substances it uses. Therefore, the third element of the program focuses on the waste products resulting from the Department's operations. ConnDOT's "Waste Management Plan" describes the various waste streams associated with facility operations; identifies applicable 'generator' permit requirements; and sets specific procedures for proper container management, manifesting, shipping and disposal of all regulated substances. The plan also contains specific provisions for spill contingencies and training.

The fourth and final element of the Risk Management Program consists of site-specific "Environmental Operating Manuals," which are being prepared for each facility. Their purpose is to provide each facility manag-

er with a system of procedural management practices for his or her particular location, thereby linking personnel operating practices with the source control structures and systems in place at that location. Each manual provides a detailed layout of the facility and its neighboring environmental setting, identifies all high-risk activities performed, describes existing source controls in place, and sets forth detailed instructions for their use and maintenance. Each manual also incorporates applicable provisions of the three statewide program manuals described previously.

CONCLUSION: DAMAGE CONTROL VS. RISK CONTROL

The title of this paper is "Connecticut's Approach to Environmental Compliance." At this juncture, it would be neither prudent nor accurate to suggest that ConnDOT's approach represents the only means to achieve and maintain regulatory compliance. Connecticut's experience to date, however, does suggest that success or failure in your own efforts will depend largely on how you would answer the following question: Are hazardous and contaminated wastes and materials best approached as environmental problems or are they really parts of a larger management problem?

Environmental problems rarely express themselves while the proverbial cow is still in the barn. This tends to force project-level or site-based responses, which in our current regulatory environment must emphasize damage control rather than risk control. Under emergency conditions, remedial response options are few and are typically less cost effective than programmatic solutions. Moreover, emergency response actions must generally be carried out under greater regulatory supervision, within a legal framework accompanied by extensive liability.

HAZARDOUS WASTE MINIMIZATION TECHNIQUES APPLIED TO SOLVENT AND OIL RECYCLING

Al Koett, *Safety Kleen Corporation*

Most waste streams from automotive-related sources, and from many industrial generators, contain primarily oil, hydrocarbon solvents, and water. While the ratios change depending on whether the waste came from a parts washer, a crankcase, or a process stream, these three components tend to predominate. Fortunately, mixtures of oil, solvents, and water can be separated for recovery using distillation, much as a petroleum refinery originally isolates those materials. For example, Figure 1 shows a boiling point curve for a used oil. The cut points show how various materials can be recovered from this single waste stream. Similarly, a parts washer solvent would be distilled with most of the stream coming over in the solvent boiling range and the oil contamination recovered as residue. In this way, waste streams are actually turned into feedstock to recovery process plants, such as oil re-refineries and solvent reprocessors. Waste minimization goals are achieved by removing these materials from the waste category, since they are collected not for disposal, but rather for recycling.

The reclamation of these wastes involves well-known process technologies. For example, in the used oil re-refining case, the following steps are applied to the feed material:

- An initial atmospheric distillation removes the water as a vapor, along with some of the light solvents. The water can be treated and used within the plant or discharged. The solvents become part of the fuel to operate the plant.

- The second distillation stage involves a moderate vacuum, which vaporizes hydrocarbon distillate materials, such as diesel fuel and mineral spirits. These also can be used as fuel for the process, or as cleaning solvents.

- The third and final distillation step utilizes high vacuum to vaporize the lubricating oil, leaving behind a tar-like material that can be sold for use as road asphalt, heavy industrial fuel, or cement kiln fuel.

- The lube oil portion is recondensed and passed over a solid catalyst in the presence of high pressure hydrogen to remove color- and odor-causing contaminants. The final product is indistinguishable from virgin lube oils.

This process description is one example of many processes that are functioning around the country and are permitted by EPA to be in compliance with RCRA, HSWA, and BIF regulations. The costs to construct and operate these systems depend on their complexity and size. However, a key to their success is the testing they perform to demonstrate that:

- The feedstock, intermediate by-products, and final products all comply with environmental regulations.

- The recovered material meets specifications, often the same specifications as applied to virgin material.
- The fuels will not cause emission problems.

- Materials incorporated into products, such as fuels sent for cement kiln use, will not negatively affect quality.

The more generators are encouraged to segregate their waste and seek recyclers who will maximize recovery of all portions of their wastes, the more true waste minimization that will occur. Not all wastes can be eliminated at the point of generation through process and feedstock changes. By combining engineering enhancements with effective utilization of those wastes that are generated, overall waste minimization impacting the environment can be achieved.

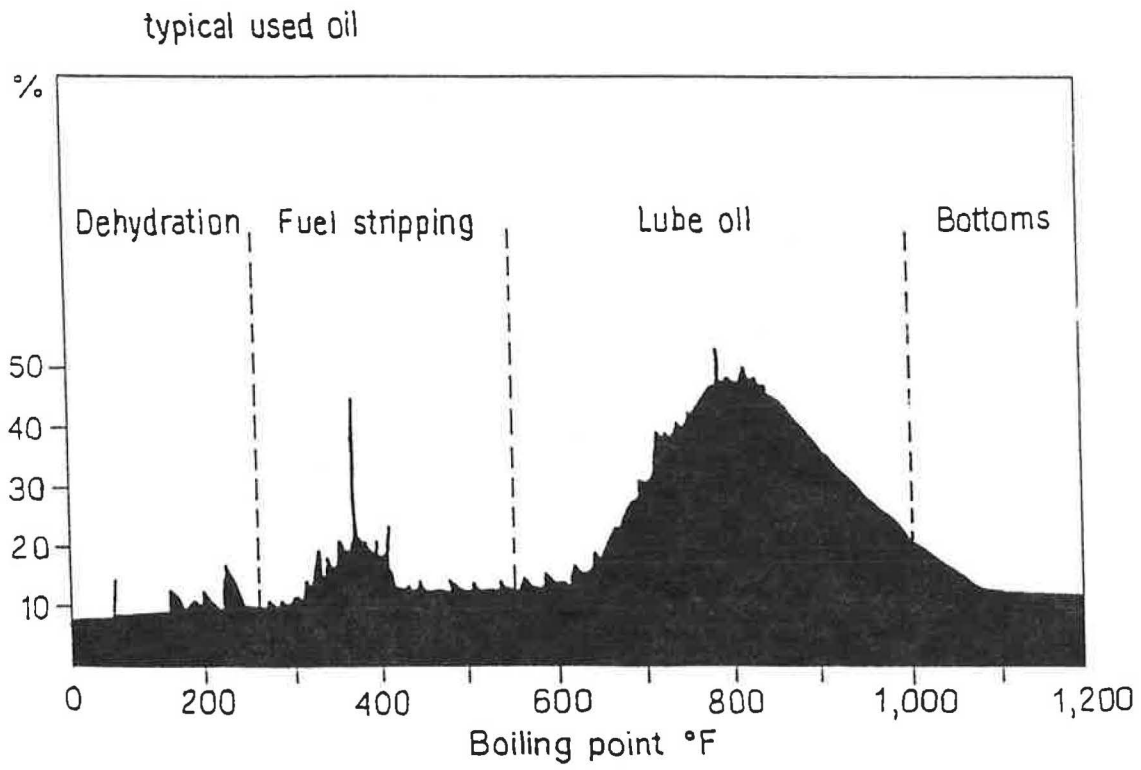

Figure 1 Boiling Point Curve for Used Oil.

SECTION IV NEW TECHNOLOGY

NEW TRANSMISSIONS TECHNOLOGY

(Abstract)

Ronald D. Doemland, *Pennsylvania Department of Transportation*, and Larry Love, *Allison Transmission*

Pennsylvania Department of Transportation (PennDOT) was selected by Allison Transmission to pilot its World Transmission (WT). PennDOT is one of ten fleets worldwide selected by Allison and the only government fleet. WT was installed in five PennDOT single axle dump trucks in April and October, 1991. The five dump trucks are located in three separate locations. The locations were selected due to their severe winters and the mountainous terrain. The dump trucks have travelled between 6,000 and 12,000 miles since the transmissions have been installed. PennDOT has experienced no problems with the transmission,s and equipment operators' evaluations have been positive.

WT product line consists of three basic model series - AD, MD and HD. The MD series, which covers medium duty applications, was the model installed in PennDOT dump trucks. The AD and HD series are slated for introduction over the next two years.

The new product features of the MD series of WT include: electronic controls, up to six forward speeds, torque converter lock-up clutch, engine driven PTO options and integral oil filters. Consumer benefits of the MD series transmission include improved performance, quieter operation, smooth and precisely timed shifts, reduced maintenance costs, and special electronics input and output features for controlling PTO operation.

SECTION V HUMAN RESOURCES AND EQUIPMENT MANAGEMENT

HUMAN RESOURCE MANAGEMENT

Edward G. Fahrenkopf, *New York State Department of Transportation*

Human resource management in today's environment is somewhat of a misnomer. Human resources, or more correctly "people," remain the most important resource that the organization has. In earlier times it was thought that for people to be productive, they had to be controlled. This was not true then and is not true now. Unfortunately, it is only recently that this has been widely recognized in this country. People are most productive when they are given the tools they need to do their job and then are left to do what they know best, with as little interference as possible. Supervisors in this atmosphere actually become coaches as well as planners of what is to be done and when it is to be done as opposed to how it is to be done. The following is an outline of some activities in which the people in the New York State Department of Transportation (NYSDOT) have been engaged.

MECHANIC RECRUITMENT

- Qualifications: NYSDOT, as does all of New York State, works within a competitive Civil Service system. The qualifications for the two levels of mechanics we currently have are four years experience for Motor Equipment Mechanic and five years experience for Construction Equipment Mechanic. The normal recruitment methods are Civil Service announcement, word of mouth and newspaper advertising, with the small weekly advertiser type being the most effective.

- Performance Examination: Each candidate is given a three part performance examination monitored by Equipment Management personnel.

- Apprentice Program: We have used in the past an apprenticeship program instead of recruiting experienced mechanics. The features of this program are:
  - An aptitude test to determine mechanical aptitude.
  - Written work processes starting at the first level of maintenance to diesel engine overhaul. This was a three year process with periodic sign off by the supervisor.
  - Classroom study at local community colleges.
  - Finally, passing the performance examination for MEM.

MECHANIC TRAINING

- Vendor Supplied With New Equipment: Each equipment contract that we award has a two part training clause:
  - Training in the operation of the equipment for the operators to include hands-on experience.
  - Minor maintenance and adjustments for mechanics.

- Factory Training: Periodically, we either send mechanics to equipment manufacturers for training on trouble-shooting and/or overhaul of major components or we have the manufacturer come to our facility to put on special training. The method used depends on the number of people to be trained. Training at the factory is usually free, with the state paying travel costs. If we have a large number to be trained, it is sometimes less expensive to pay to have factory trainers come to our facility instead of paying travel costs.

- Supervisor With Videos and Workbooks: Some years back we purchased several "Sight on Sound" slide training programs, with a slide projector in each region. Then we also gave instructor training to a shop supervisor in each region. This has since evolved to the use of videos, some of which are created in-house, but the majority of which are either purchased or are provided by vendors with new equipment.

- On Site by Consultant Contractor: With the labor union, via Joint Labor Management Committee, NYSDOT has contracted with a consultant trainer that travels around from region to region putting on intensive one-day training sessions on hydraulics, diesel engine diagnosis, automotive electrical systems and computerized emission control systems. This method of providing training to keep the skilled technicians up-to-date is cost effective and has been well received by the employees.

MECHANIC JOB ENRICHMENT PROGRAM

In 1990, a "Mechanic Job Enrichment" program was started in one region as a pilot. The goal of the project was to develop, implement, monitor and evaluate a work procedure for mechanics that would have the mechanics who work in the main repair facility in a region become more involved in the total process, including direct communication with the mechanics in the counties and the operators of the equipment. Where previously there was one person responsible for quality control in the repair facility, this was changed to having each mechanic be responsible for his own quality control. This reduced "come backs" to zero after a "shake down period" of approximately six months. There was a cross orientation of employees to have the people work closer and understand the needs and functions performed by fellow employees. Demands for better scheduling and pre-scheduling of repair parts resulted in faster turnaround of repairs. An unforeseen benefit was a desire by the mechanics to compete with outside commercial repair shops.

QUALITY CIRCLES

The NYSDOT has added the implementation of Quality Circles (QC) to its list of tools to enhance overall productivity. Through the efforts of the Department's Human Resource Development Bureau, a series of Train-the-Trainer sessions and training of QC facilitators was started. As with the majority of employee involvement programs, it is most successful if it is a voluntary program. The program has flourished more in some areas than others.

INNOVATION PROJECTS

In May of 1990, a pilot Innovation Workshop was held with Equipment Management employees from Region I. Approximately 50 employees participated. From this first workshop, ten innovation projects were started. From this small beginning and a grant from the Joint Labor Management Committee of the Civil Service Employees Association, workshops were held in each Region, training 400 employees. Projects were limited to what could be accomplished within three months and accomplished by the employees doing the job. The program verifies the belief that the people closest to the job are the ones who know how to improve it.

WELLNESS INCENTIVE PROGRAM (SICK LEAVE REDUCTION)

With an increasing fleet size and a shrinking work force, a pilot "Sick Leave Reduction" program was started by the Equipment Management Division in 1989. The goal of this project was to increase the amount of time employees were at work. There was a simple incentive for those employees who used less sick or injury leave than the statewide average. An employee who used five days or less was given a $100 award; for six days $50; and seven days $20. The incentive was aimed at the marginal sick leave user. In fiscal year 1988/89, the Division had a sick leave rate of 10.3 days per employee. In fiscal year 89/90, the rate fell to 8.4 days for the first year of the program. The rate for the second year was 8.8 and 8.7 for the third and final year. The program cost approximately $24,000 per year and produced savings in commercial repair of approximately $125,000, for a net savings of $101,000 per year.

SAFETY COMMITTEE

NYSDOT has a multi-facet approach to promoting safety in the work place. There is an intensive safety awareness effort, a system of safety awards, tailgate safety meetings and a network of "safety committees." These committees are comprised of rank and file employees with a charge of duty to identify any potential safety problems or situations, propose solutions if possible, and work with management to implement the solutions.

CONTINUOUS IMPROVEMENT "QUALITY"

In New York State, the Governor's Office of Employee Relations is coordinating the Total Quality Management movement for all agencies in the state. There has been and is continuing to be a series of productivity seminars for management personnel focusing on quality management. QtP ("Quality through Participation) is New York's label for Total Quality Management. NYSDOT has been designated to be a pilot agency to work with Xerox Corporation to implement a QtP system. The Department is currently in the formulation process.

MAINTENANCE OPERATIONS RESOURCES INFORMATION SYSTEMS (MORIS)

Ronald D. Doemland, *Pennsylvania Department of Transportation*, and James A. Goodchild, *KPMG Peat Marwick*

During the 1970s, the Pennsylvania Department of Transportation (PennDOT) developed a Maintenance Management System, an Inventory Management System and an Equipment Management System. While these three systems interfaced with the Accounting system, there was little integration among the three systems. In the early 1980s, PennDOT began to develop MORIS - Maintenance Operations and Resources Information System. MORIS was fully implemented on July 1, 1986, and consisted of three fully integrated sub-systems - Highway, Equipment and Materials. MORIS has provided the Department the capability of planning, monitoring and controlling maintenance operations and resources.

Some of the major benefits PennDOT has realized since the implementation of MORIS have been:

- Reduced clerical effort
- Increased accuracy and reliability of maintenance data
- Improved control over inventory
- Accurate forecasts of material needs
- Improved resource planning
- Lower equipment obsolescence costs
- Better operating cost control

Just a few of the key features associated with MORIS include:

- Annual planning integrated with analysis of pavement condition
- Resource balancing
- Single source for all input
  - Payroll and Production Data from the same document
  - All activity (equipment, material and labor) recorded by the same person.
- Preprinted payroll documents
- Mechanized garage work orders
- Equipment retirement analysis
- Mechanic performance analysis

The Equipment subsystem of MORIS tracks the history of all equipment from acquisition through disposition, as well as monitoring the equipment performance during its life. While the Equipment subsystem contains many features, three of the key features are the Garage Repair, Equipment Scheduling, and Accounting Modules.

- The Garage Repair Module maintains the history of the equipment and provides the garage manager the repair needs while allowing him to generate the repair work order that he wishes while the preventive maintenance work order is automatically generated by the system.
- The Equipment Scheduling Module tracks equipment use, reserves equipment for use and maintains usage standards. Equipment is automatically scheduled for preventive maintenance and fleet assignments are tracked.
- The Accounting Module records equipment purchase costs and maintains depreciation schedules. All usage, repair and operational costs are maintained and passed to the Financial System.

The key feature of the Highway subsystem is the Planning and Scheduling Module. The first step in the planning and scheduling process is to input the information from the road condition survey conducted by each Assistant County Manager. As each deficiency is input, the systems know the route number and the maintenance activity number that will eventually be used to document the completed work. This process continues as the Assistant Manager surveys his roads and builds an inventory of work to be completed.

The next step of the Planning process is to develop the Period Plan (4 months). The Manager, on line, selects the work from his inventory he would like to accomplish in the period. The system then selects the work items by activity and state route. Total crew days planned for each foreman is calculated. Our guideline is to include enough work on the Period Plan to account for at least 70% of the crew days available. Inclement weather and emergencies account for the remaining 30% of the plan.

The next step in the planning process is for the Assistant County Manager to develop his weekly plan. By reviewing his period plan, he selects one or two activities per day, per crew. The system will then generate a preprinted daily payroll for each day of the next week as well as a weekly plan summary for each foreman. The foreman now knows what to do the following week and has his payrolls that contain much of the coding preprinted by the system. After the work is

accomplished, production hours and production units are data entered.

The key to successful development of MORIS can be attributed to the following:

- Field involvement in the requirements, definition and conceptual design phases of the project.
- Constant communication with the field personnel and presentations to field managers during the two years of development.
- Establishment of a team of Department employees and KPMG Peat Marwick representatives to develop and implement the system.

APPENDIX A - WORKSHOP PROGRAM

9th EQUIPMENT MANAGEMENT WORKSHOP

Sheraton Imperial Hotel & Convention Center
Research Triangle Park, North Carolina

Tuesday, June 16, 1992

9:00 - 9:30 a.m. **OPENING SESSION**
Doug Nielsen, *Arkansas State Highway and Transportation Department*, and *Chairman of TRB Committee on Equipment Maintenance*, presiding

WELCOMING REMARKS

- William G. Marley, Jr., State Highway Administrator, *North Carolina Department of Transportation*
- John M. Burns, Director of Equipment and Inventory Control, *North Carolina Department of Transportation*

Development of Workshop Research Problem Statements, Doug Nielsen

9:30 a.m. - 12 noon **EQUIPMENT STANDARDIZATION**
Arlen T. Swenson, *John Deere & Company*, presiding

Equipment Specifications Guide, Arlen T. Swenson
Comparison of Truck Specifications, Wayne Layman, *Mississippi State Highway Department*

10:30 - 10:45 a.m. **BREAK**

Standardization of Spreader Specifications, Robert Henderson, *Swenson Spreader Company*
Comparison of Equipment Paint Specifications, Glenn Hagler, *Texas Department of Transportation*
Report on Regional Equipment Managers' Conferences, Robert W. Kuenzli, *Consultant*

12:00 - 1:00 p.m. **LUNCHEON**

1:00 - 5:00 p.m. **EQUIPMENT RESEARCH**
L. David Minsk, *Strategic Highway Research Program*, presiding

Overview of SHRP Maintenance Program, S.C. Shah, *Strategic Highway Research Program*
Automated Pothole Patcher, James R. Blacha, *Basic Industry Research Laboratory at Northwestern University*
Joint & Crack Filling Robot, Steven A. Velinsky, *University of California at Davis*
Driverless Shadow Vehicle, Mark Smith, *ENSCO, Inc.*
Salt Spreader with Truck-Mounted Attenuator (TMA), James Crowley, *Energy Absorption Systems, Inc.*

2:45 - 3:00 p.m. **BREAK**

Portable Equipment to Measure Effectiveness of Maintenance Treatments, Brian Cox, *Strategic Highway Research Program*
Improved Snowplows, Kynric M. Pell, *University of Wyoming*
Low Application Rate Salt Spreaders, L. David Minsk, *Strategic Highway Research Program*
Truck-Mounted Attenuator Research, Lindsay Griffin, *Texas Transportation Institute*
European Equipment Research, Brian E. Cox, *Strategic Highway Research Program*

Wednesday, June 17, 1992

9:00 a.m. - 2:45 p.m. **ENVIRONMENTAL ISSUES**
Thomas H. Maze, *Iowa State University*, presiding
Alternative Fuels - Legislative Mandates, Initiatives and Issues, Thomas H. Maze
Texas' Aggressive Alternative Fuels Program, Don Lewis, *Texas Department of Transportation*
Conversion, Flexible Fuel, and Dedicated Engines: Emissions Properties, Costs, and Driving Range, Richard Bechtold, *E. A. Mueller, Inc.*

10:30 - 10:45 a.m. **BREAK**

Present and Future Light-Duty Engines, Todd Krenelka, *Battelle Laboratories*
Present and Future Heavy-Duty Engines, Peter Jenkins, *University of Nebraska*

12:00 - 1:00 p.m. **LUNCHEON**

Environmental Regulations and Issues Affecting Garage Waste, John Konefes, *Center for Waste Reduction at the University of Northern Iowa*
Compliance with Environmental Equipment Requirements in Connecticut, Kenneth Daly, *Connecticut Department of Transportation*
Recycling and Disposal of Fluid/Solid Wastes, Al Koett, *Safety Kleen Corp.*

2:45 - 3:00 p.m. **BREAK**

3:00 - 5:00 p.m. **NEW TECHNOLOGY**
Thomas H. Maze, *Iowa State University*, presiding
Diesel Engine After Treatment Options to Meet the 1994 Emissions Standards, Arnie Carlson, *Donaldson Company, Inc.*
Facility Requirements To Accommodate Alternative Fueled Vehicles, Robert Schmelz, *Gannett Fleming, Inc.*
New Transmissions Technology, Ronald D. Doemland, *Pennsylvania Department of Transportation*

6:00 - 9:00 p.m. **DINNER**

Thursday, June 18, 1992

9:00 - 10:45 a.m. **HUMAN RESOURCES AND EQUIPMENT MANAGEMENT**
Leland D. Smithson, *Iowa Department of Transportation*, presiding
Human Resources Management, Edward G. Fahrenkopf, *New York Department of Transportation*

9:45 - 10:00 a.m. **BREAK**

Fully Integrated Equipment Management Systems, Ronald D. Doemland, *Pennsylvania Department of Transportation*

10:45 - 11:30 a.m. **RESEARCH PROBLEM STATEMENTS**
Doug Nielsen, presiding
Development of Equipment Maintenance and Management Problem Statements, Workshop Participants

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