TRANSPORTATION RESEARCH
CIRCULAR

Number 475 July 1997

11th Equipment Management Workshop

TRANSPORTATION RESEARCH BOARD / NATIONAL RESEARCH COUNCIL

TRANSPORTATION
RESEARCH
CIRCULAR

Number 475, July 1997
ISSN 0097-8515

11TH EQUIPMENT MANAGEMENT WORKSHOP

June 23-26, 1996
Syracuse, New York

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

In cooperation with:

NEW YORK STATE DEPARTMENT OF TRANSPORTATION and
FEDERAL HIGHWAY ADMINISTRATION

Committee on Equipment Maintenance
Doug Nielsen, Chair

Edward H. Adams
Francis E. Allred
Dwight R. (Dick) Berkey
William J. Buglass
John M. Burns, Jr.
Ronald D. Doemland
Edward G. Fahrenkopf
Richard W. Hunter
Robert W. Kuenzli
Thomas H. Maze
L. David Minsk
Gerald L. Ray
Leland D. Smithson
Arlen T. Swenson
Walter J. Tennant, Jr.
Thomas Wald

Frank N. Lisle, TRB Staff Representative

Subscriber category
IIIC maintenance

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

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, motivation and safety, equipment replacement decisions, inventory control, commercial driver's license requirements, alternative fuel engines, environmental safety, privatization, electronically controlled diesel engines, and other related issues. Eleven 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 11th Equipment Management Workshop was sponsored by the Transportation Research Board Committee on Equipment Maintenance in cooperation with the New York State Department of Transportation and the Federal Highway Administration in Syracuse, New York, June 23-26, 1996. The proceedings of this Workshop are included in this *Circular* and structured around the following topics:

Government Regulations: The Changing Scene
International Equipment Technology
Human Resource Management
Safety
Specialty Equipment
Purchasing and Leasing
Future Equipment Technology
Developments in Equipment Management Systems
Reports from Regional Equipment Managers' Meetings

CONTENTS

CHALLENGES FACED BY TRUCK ENGINEERS IN THE MID-1990s

Ken Kelley
Roads & Bridges Magazine

ABSTRACT

This paper provides a brief overview of how truck engineers and designers are turning to highly sophisticated technology for assistance in meeting increased market and regulatory demands for vehicle improvements.

INTRODUCTION

While working on the December 1995 issue of *Roads & Bridges Magazine*, a review of what happened on the truck scene during the year seemed appropriate. The review was published under the headline: "The Year of the Engine Engineer." It went over fairly well. At least, no transmission engineers called to complain. The 1995 headline serves as a point of departure for this talk. Early on, it was determined that the time frame for the talk should be adjusted to look forward to what is happening this year. With brakes that feature electronic antilock controls being fine tuned this year for mandatory installation in all big trucks from next year through 1999, a headline such as "The Era of the Electronics Engineer" suggested itself. Since some recent technical changes in trucks, notably fuel economy moves, have their roots in advances first noted before 1995, it was decided that this talk be widened to survey all the mid-1990s. After a look back to the year of the engine engineer in 1995 and a brief glimpse back to earlier developments, we will close with an up-to-the-moment look at what truck technical people are doing this year.

As noted, 1995 has gone into the truck history books as "The Year of the Engine Engineer." While it must be said that powerplant people made most 1995 headlines, it should be added that governmental regulators were out there vying for a share of the spotlight. For high drama, it is difficult to top the 1995 work of the engineers at the diesel engine manufacturers. Three lines closed out last year with new engines that were their strongest-ever truck diesels, the 500-horsepower unit from Detroit Diesel, a 525-horse offering from Cummins and a 550-horsepower Caterpillar product. With high fuel prices showing no signs of going away, the high horsepower engines were justified as the makers' response to customer requests for added strength to get difficult jobs done efficiently. Engine engineers were doing far more than "building them stronger" in 1995. Developing variations of existing engines that operate on alternative (nonpetroleum) fuels as a way to reduce air pollution and curb dependence on foreign oil was a massive effort.

Work on "alt" fuels sent researchers off in many directions. While Mack people were studying compressed natural gas or CNG as the fuel for a test E7 diesel engine, Detroit Diesel researchers were working with Ford engineers on a test of a CNG-fueled Series 60 powerplant for bulk newspaper delivery in the Los Angeles area. High costs are one of the problems with many alt fuels. As one engineering executive explained, a difficulty can be estimating the cost of auxiliary parts, such as fuel tanks, which have not yet been produced in volume for engines using the unusual fuels. At one extreme, alt fuel plans can be as obvious as one by Cummins people. Reacting to operators' requests for added power, they moved up the top horsepower ratings of the firm's L10 natural gas engines to more robust 280 and 300 numbers.

More complex was the effort of the truck producer, Navistar, and the oil firm, Amoco, working with two European companies in a program that delivered "a new, ultra-low emissions alternative fuel for use in diesel engines." The product was said to be "predominantly dimethyl ether or DME which is converted from natural gas or coal and other feedstocks." Those who worked on the new fuel said "DME can eliminate exhaust smoke and greatly reduce other exhaust pollutants while reducing engine noise." The alt fuel was said to be able to meet California's demanding 1998 emissions requirement "without the use of exhaust after treatment or catalytic converters." While California's 1998 exhaust rule, as is frequently the case, is more strict than those for the rest of the nation, preparing for a further tightening of emission limits for the rest of the nation in 1998 was another reason why truck engine engineers were busier than usual in 1995. The pressure is on to cut oxide of nitrogen emissions by 20 percent to meet the 1998 national standard. No one is saying exactly what will be done but confidence in meeting the standard is widely expressed.

Last year, both Caterpillar and Navistar were working with Hydraulic Electronic Unit Injection fuel injection systems for trucks just a cut below the strongest. Cat offered the system in its new 3116 diesel which has

ratings of 170 to 275 horsepower. At Navistar, a similar system was used on the line's first electronic diesel which develops 250 to 300 horsepower. The beauty of these advanced systems is that they do an acceptable job of curbing emissions without aid of catalytic converters or other exhaust after treatment.

Volvo's latest offering in the diesel field is the electronic VE D12 which turns out 310 to 415 horsepower. Other important engine programs have had Detroit Diesel cooperating with Navistar on powerplant development and with Mercedes-Benz of Germany in designing diesels for the Mercedes subsidiary here—Freightliner.

Improved fuel economy, a need spawned by the oil crises of the Seventies dominated technical changes in trucks in the Eighties and early Nineties. On-off engine fans that operate only when needed for cooling, powerplants with reduced operating speeds, more efficient gearing as well as aerodynamic streamlining to curb wind drag were the most noticeable developments. There was a time about 1985 when the "experts" said that aerodynamic changes had gone about as far as they could in cutting fuel consumption. Every couple of years since, at least one truck maker has unveiled a restyled model with better aerodynamics that cut fuel bills even more. By introducing two very aerodynamic big truck lines, Louisville vocational units and AeroMax 9500 over-the-road tractors, Ford dominated the 1995 new model scene in the heavy truck field and proved that further aerodynamic gains are possible.

No one introduces a new model heavy truck these days without pointing out how the designers have thoroughly consulted with those all-important drivers on how the vehicle should be built. Ford made a novel point about its new models unveiled in 1995, noting that designs for most recent truck models were based on measurements of average drivers obtained in studies conducted during the World War II era, Ford said it measured current drivers and based its latest designs on those figures. Increased seat travel and more "belly" room were the big changes.

Turning now to what is going on in truck development this year, the big headline maker can be traced to a 1995 decision by the National Highway Traffic Safety Administration, requiring installation of brakes with electronic antilock capability on all new big trucks and trailers at varying dates between next year and 1999. Bendix, Midland and Rockwell WABCO have been gearing up to supply the hardware. In a recent move, Eaton and Bosch have decided to set up a joint effort to supply antilock brakes to the North American market. Antilock systems got a blackeye as they were found wanting when required in 1975. This time they are being mandated only after extensive federal testing. The current hardware has drawn few complaints so far, although there are those who have their doubts about how antilock systems in tractors and trailers should be linked. Most 1995 objections to the systems were aimed at antilocks installed in light trucks and cars. Many have been dismissed with observations that vehicle operators have not taken the time to learn how to use antilock systems properly.

Systems engineering is a major trend in truck development today. It is playing a key role in putting the finishing touches on big truck antilock systems. In a few words, it calls for designing parts that will be used together at the same time that other parts which will be used in the system are developed. Ideally, all parts that go into the system are preassembled as a system before going on the truck. The plan is designed to guard against mistakes as system parts are put into the truck. It makes sense when all of the wires, sensors, tone wheels and other antilock parts needed in an axle are put in the axle before the axle is shipped to the truck assembly plant. Errors in assembly were blamed for some of the antilock problems of the Seventies.

Computer-like systems which enable major truck components to diagnose their own malfunctions have been built into many components introduced in recent years. That trend has relieved the concerns of those who wondered how mechanics could be trained to troubleshoot the new electronic marvels which have come to dominate truck products in recent years.

For those who want to see something farther out than "automated diagnostics," truck industry technical experts are working on "prognostics." This involves using computerized "artificial intelligence" to project how a truck component will fail and when. The rubber industry has taken computerization of trucks a step further by burying computer chips in tire treads. It is a great way to pick up information from the point where the rubber meets the road. Futurists in the truck industry have been fascinated with radar since it proved most useful during World War II. Could not its ability to "see" through the night and storms be used to head off traffic accidents, they asked. Radar-activated braking is not here yet but Eaton Corporation and Delco Electronics have started moving toward that goal. Already they have reported progress in overcoming one of the admitted problems of truck operation—the inability of the driver to see what is going on in certain "blind spots" around the vehicle. In other safety efforts, the Volvo truck operation in North Carolina and its parent company in Sweden have been installing daytime running lights on trucks and researching the potential benefits of electronically actuated air bags in heavy trucks.

INITIATION AND IMPLEMENTATION OF AN ALTERNATIVE FUELS PROGRAM

Glenn Hagler
Texas Department of Transportation

The Texas Department of Transportation (TxDOT) has initiated an aggressive plan to convert its on-road motor vehicle fleet of 9,000 vehicles to alternative fuels. State legislation passed in 1989 requires that TxDOT have 90% of its fleet converted by 1998. This undertaking has radically changed the way the Department both purchases and manages its fleet and thus has required major changes in the planning, procurement and use of its vehicles. The initial implementation of an alternative fuels program should consider and account incentives in energy abundance, environmental protection and economic concerns; initiatives in (Federal) Clean Air Act Amendment, Energy Policy Act and individual state legislation; and barriers in equipment cost, fuel availability, market inertia and underdeveloped infrastructure.

INTRODUCTION

Texas passed clean air legislation in 1989 (and again in 1995) that significantly altered the manner by which the Texas Department of Transportation (TxDOT) could purchase and fuel its motor vehicles. These laws, which became effective September 1, 1991, established a means to use the vast natural gas reserves available within the state while simultaneously reducing harmful exhaust emissions. They require all state agencies consisting of 15 or more vehicles to use alternative fuels in their motor vehicle fleet. They also require that TxDOT have 90% of its fleet converted to alternative fuels by 1998.

REGULATION

Texas regulatory agencies have approved five alternative fuels that meet the intent of Texas clean air legislation: natural gas (compressed-CNG/liquid-LNG), liquid petroleum gas (LPG), methanol, ethanol and electricity. TxDOT currently considers only CNG and LPG as viable alternative fuels for its fleet operation.

The law mandates four critical milestones. After September 1, 1991, Texas governmental agencies may only purchase or lease motor vehicles that are capable of using alternative fuels. As of September 1, 1994, the fleet must consist of not less than 30% alternative fueled vehicles (TxDOT exceeded compliance at 32%); by September 1, 1996, this percentage increases to 50% and to 90% by September 1, 1998. TxDOT has met or plans to meet and exceed these requirements.

The law affects 9,000 on-road TxDOT motor vehicles. TxDOT has placed into service more than 4,000 alternative fueled vehicles to date that represent more than 44% of its on-road fleet. TxDOT plans to purchase or convert more than 4,500 vehicles to alternative fuel use by 1996 and nearly 9,000 by 1998.

INCENTIVES

In the last few years, energy security and environmental concerns have become prominent incentives for transportation policy and planning. Dependence on foreign oil supplies and concern over urban pollution and global warming have led to a nationwide trend away from petroleum-based modes of transportation.

INITIAL BASIS FOR THE LAW

Texas produced 6.4 trillion cubic feet (181 billion cubic meters) of natural gas in 1995 that amounted to 32% of total US production. In addition, Texas has 35.9 trillion cubic feet (1.02 trillion cubic meters) of dry proven reserves. With this abundant natural resource as an incentive, Texas passed clean air legislation in 1989 that mandated the use of natural gas or other clean air alternative fuel in state agency motor vehicles.

The intent of the state legislature in passing this law was threefold: to clean the environment, to develop a market for Texas natural gas and to stimulate the Texas economy. As an example, one trillion cubic feet (28.3 billion cubic meters) of natural gas will provide fuel for one year for approximately eight million vehicles. In promoting a Texas resource that benefits both the economy and the environment, Texas hopes to become a leader in the use of alternative fuels.

INITIATIVES

As motor vehicles are the largest single source of pollution, several initiatives have been undertaken to

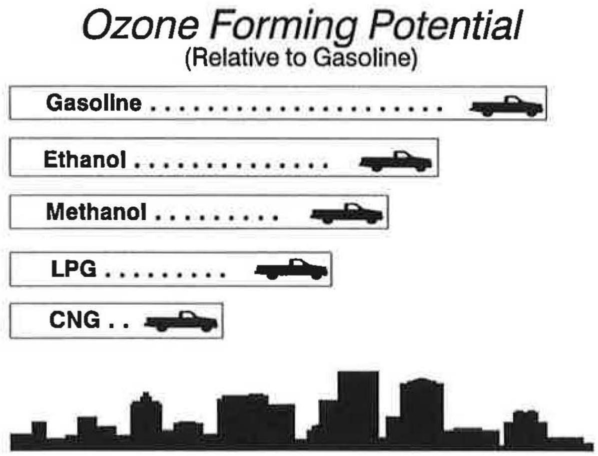

FIGURE 1 Ozone forming potential: Alternative Fuels Promises and Pitfalls; National Conference of State Legislatures 1991 Annual Meeting, Orlando Florida.

replace petroleum fueled vehicles with alternative fueled vehicles.

The Clean Air Act Amendment of 1990 (CAAA 1990) became the primary driver to move the nation away from petroleum-based fuels. The Energy Policy Act of 1992 reinforced the intent of CAAA 1990 by mandating specific milestones for governmental fleets in the use of alternative fuel vehicles. Individual state legislation continues to increase the requirement for the use of alternative fuels.

It is imperative that all levels of government legislation be monitored on a continuous basis.

CLEAN AIR ACT AMENDMENT OF 1990

The Clean Air Act Amendment of 1990 became law after 11 years of deliberation. The law establishes twenty-one areas throughout the United States in nonattainment of National Ambient Air Quality Standards. By mandating that these areas come into compliance, the Amendment provides a strong impetus for use of low emission alternative fuels.

CAAA 1990 focused primarily with regard to emission standards and clean air defining specific transportation control measures directed toward emission reduction. By 1998, most governmental fleets operating more than 10 vehicles weighing up to 26,000 pounds (11,794kg) in these areas will be required to purchase up to ½ of all replacement vehicles capable of operation on an approved alternative fuel. Figure 1 shows the benefits of using various alternative fuels compared with the baseline reference for ozone forming potential of gasoline.

Targeted for concern with effect upon alternative fuel considerations are the ozone/carbon monoxide classifications in nonattainment counties. CAAA 1990 affects four major nonattainment metropolitan areas within the state: Houston/Brazoria/Galveston, Beaumont/Port Arthur, El Paso and Dallas/Fort Worth. Figure 2 compares the relative percentage contributions between mobile and stationary volatile organic compound (VOC) sources in the nonattainment areas.

The dates proposed for the required percentage achievement of alternative fueled vehicles are much later than those set forth in Texas clean air legislation (Texas Senate Bill 740, 74th Legislature). Other areas of amendment concern include the requirement for the use of oxygenated fuels and the reduction of particulate matter.

NONCOMPLIANCE

According to the Environmental Protection Agency, the enforcement arm of the Clean Air Act Amendment, operators not in compliance with the law could pay as much as $25,000 a day.

ENERGY POLICY ACT OF 1992

The Energy Policy Act of 1992 was designed to encourage domestically produced fuel usage in both mandate and incentive provision for alternative fueled vehicles. The Energy Policy Act, broader in fleet requirement definition than CAAA 1990, will affect 125 metropolitan areas. The implementation of requirements set forth in this Act

VOC Emission Sources

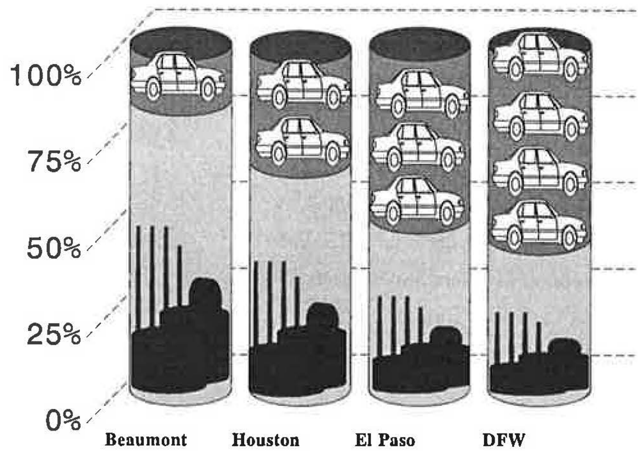

FIGURE 2 VOC Emission Sources: Texas General Land Office, 1995.

began in FY1993 for federal fleets with state fleets and alternative fuel providers to begin alternative fuel vehicle (AFV) purchase in MY1996 and possible private and municipal fleet AFV acquisition in MY1999. Alternative fuel providers are defined as gas and electric utilities, alternative fuel and large oil companies that conduct a substantive portion of alternative fuel business.

STATE LEGISLATION

Many states due to their own internal agendas be it pollution control and/or economic considerations have elected to incorporate alternative fuel legislation that supersedes the mandates of the Clean Air Act Amendment. Sixteen states presently have mandatory alternative fuel vehicle requirements for procurement of replacement governmental vehicles. They include California, Colorado, Iowa, Missouri, New Mexico and Texas. Twenty states have no alternative fuel program. The remaining fourteen states have incentives offered for converting vehicles to operate on alternative fuels. The definition for "alternative fuel" varies from state to state.

TEXAS SENATE BILL 740/769

Texas Senate Bill 740 mandates the use of alternative fuels. It requires certain entities to purchase alternative fuel vehicles and to increase over time the percentage of their fleet that must be capable of using alternative fuels. (Senate Bill 769 affects municipalities later in the decade.)

Effective September 1, 1991 state agencies must purchase or lease new vehicles capable of using these alternative fuels. Additionally, as of September 1, 1994, the fleet description must consist of not less than 30% alternative fuel vehicles (TxDOT achieved 32% by September 1, 1994). This percentage increases to 50% in two years and to 90% after four years.

The Texas Natural Resource Conservation Commission has defined which fuels qualify as an alternative fuel. Currently these include natural gas (CNG/LNG), liquefied petroleum gas (LPG), methanol, ethanol and electricity. The 1998 deadline applies only if the Texas Natural Resource Conservation Commission determines in 1996 that the program has been effective in reducing area total annual emissions. Table 1 compares the principal milestones of Senate Bill 740 with that of the Energy Policy Act.

TEXAS

To better appreciate the impact of Senate Bill 740 upon the Department and probable impact of the Clean Air Act Amendment upon the state is to begin with a description of how big is Texas. The second largest state in the union is called home by more than 16 million people driving to work every day in 12 million vehicles on 293,000 miles (471,525km) of highways. The state will need a large refueling infrastructure to make alternative fuels viable; 293,000 miles will demand frequent refueling locations.

TABLE 1 PRINCIPAL MILESTONES OF SENATE BILL 740 AND ENERGY POLICY ACT

ENERGY POLICY ACT

Principal Milestone Comparative to SB740

	Energy Policy Act	TEXAS SB740
1992		
1993	Federal fleet purchase: 5,000 AFV	
1994	Federal fleet purchase: 7,500 AFV	*AFV: 30% of state fleet*
1995	Federal fleet purchase: 10,000 AFV	
1996	AFV: 25% of state fleet	*AFV: 50% of state fleet*
1997		
1998		*AFV: 90% of state fleet*
1999	AFV: 75% of state fleet	
2000	AFV: 75% of federal fleet	

TxDOT RESPONSIBILITY

With an annual budget of $3.2 billion, the Department's 15,000 employees are responsible for maintenance of 293,000 miles (471,525km) of highways. This is the largest amount of state managed mileage pavement in the United States. The Department has subdivided the state into 25 districts consisting of 430 onsite refueling locations.

IMPACT UPON TxDOT

The impact of Senate Bill 740 upon the Department is great. The TxDOT fleet consists of more than 17,000 units of equipment with a replacement value worth more than $400 million. Of these, 9,000 are classified on-road, 3,000 off-road and the balance as nonmotorized equipment. To meet the 90% criterion by 1998 this Department will either convert to or purchase more than 8,000 alternative fueled vehicles. The size of this task is apparent when one realizes that this law requires the Department to purchase more than 3,500 new alternative fueled vehicles between the present and 1998.

BARRIERS

Four major barriers persist in preventing the alternative fuel market from flourishing.

The high expense in both vehicle conversion and fuel station access for most alternative fuels have limited the number of operators changing fuel type. Costly vehicle conversion when coupled with nominally cheaper fuel price offset does not readily meet short term payback and cost effectiveness requirement in many applications.

The widespread availability of most alternative fuel is near nonexistent. Even with access the use of such fuel as in compressed natural gas is deterred when long range is a requirement. Driving very far from the central fuel depot becomes an exercise in fuel allocation to assure a safe return.

Market inertia gives rise to an underdeveloped fuel support structure. Market interest currently exists in the public sector where visibility and acceptance have been limited. A broad selection of alternative fuels has not allowed for the singular momentum necessary within the private sector to develop the required infrastructure necessary to support any alternative fuel use on a broad scale.

Implementation

An ordered approach to implementing Senate Bill 740 has been undertaken by the Department. The process has been summarized as

- Gathering of information;
- Understanding of requirement;
- Assessment of available alternative fuel technology;
- Performance of life cycle cost/benefit analysis on all potential choices;
- Gainful experience of potential choices;

- Development of sound procurement specifications; and
- Investigation of different technologies and their respective exhaust emissions.

Although the fuels-of-choice are more tightly defined in Texas than those allowed under the Clean Air Act Amendment (by state law only natural gas, liquid petroleum gas, methanol, ethanol or electricity are allowed for large state agencies) these basic steps can be applied to any of the fuels allowed within the Clean Air Act Amendment or the Energy Policy Act.

Gathering of Information

The formal basis for effectively constructing any program lies in the proper gathering of available information. Thus, the most important step in the implementation process is the familiarization with all aspects of the alternative fuels arena. Alternative fuel selection yields to its local availability, job environment suitability and its physical property characteristics. Storage, both on-vehicle and at refueling location, is different for each fuel type. Some fuels are liquid at ambient temperature and pressure, some are liquid when under moderate pressure and some are liquid only when supercooled. Other fuels are stored in a gaseous state requiring bulky storage tanks.

The daily driving requirement of the vehicles in question must be analyzed and their drive range computed so that a reasonable amount of fuel can be carried onboard to complete daily demand. Vehicular performance could be impaired or enhanced due to the new fuel type required.

Vehicle conversion may be necessary for the selected fuel. Cost determination of conversion to existing equipment versus purchase of replacement equipment should be assessed.

Knowledge of all regulations pertaining to emissions control and alternative fuel use is mandatory. Federal, state and municipal mandates will require vigilant attention to implementation timetables and compliance to fleet size percentages. State legislation, as found in Texas Senate Bill 740, can supersede timetable requirements as proposed in CAAA 1990. Different cities of the US fall into nonattainment area by law and consequently fuel type requirement may be affected.

Many alternative fuel products are currently in use and it is important they meet test in both proof of operation and product safety. A leader recognized in this field is the California Air Resources Board (CARB) and special attention to their emission certified list of approved products for certain alternative fuel conversion kits is critical. Major industrial associations have also published lists of approved and recommended equipment for alternative fuel use germane to their industry.

All aspects of the conversion system components along with the fuel storage cylinders and their installation should comply with the safety standards required by the National Fire Protection Association (NFPA) Pamphlets 52 and 58, the American National Standards Institute (AGA/ANSI/NGV1; AGA/ANSI/NGV2; AGA/ANSI/NGV3 proposed, AGA/ANSI/NGV4 proposed), the American Society of Mechanical Engineers (ASME) and the U.S. Department of Transportation (USDOT). Professional organizations such as the Transportation Research Board (TRB) and the Society of Automotive Engineers (SAE) have vast resource information on all alternative fuels currently in use.

The singular most valuable asset available to the fleet manager today is the user experience of others. In visiting operations already converted to alternative fuel(s) one can determine more readily what works and what does not work.

Understanding of Requirement

The understanding of requirement which links alternative fuel selection to operational need lies in accurate fleet assessment. Likewise, the understanding of requirement which links alternative fuel selection to overall cost effectiveness lies in certain aspects of fleet assessment such as vehicle number per refueling site, vehicle drive routine and useful life expectancy.

Two aspects should not be forgotten and when addressed early in the program can be a major contributor to the overall cost effectiveness. Depending on the type of alternative fuel selected the operational and maintenance facilities used to provide upkeep for these vehicles may have to be modified. Modifications could include new or expanded ventilation systems, gas leak detectors, automatic door opening systems, alarms, etc. Personnel involved in the operation and maintenance of the vehicles will have to be trained. The training program should include operator familiarization with safety, mechanical repair and preventive maintenance topics.

The data gathered from the Department 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-per-day 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.

The breakdown of these vehicles by classification showed an even distribution between light-to-medium

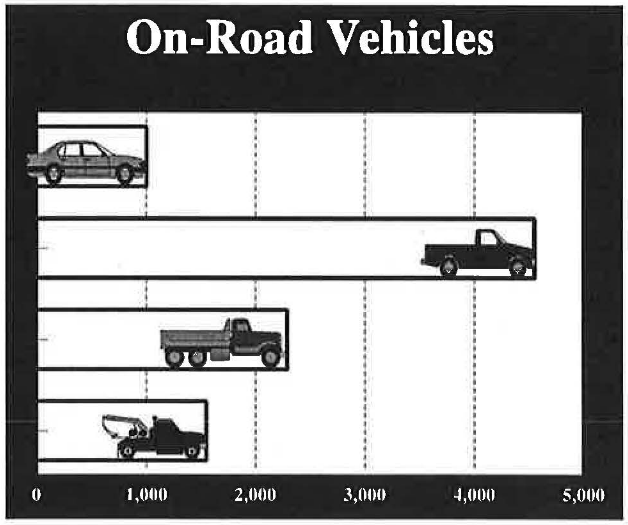

FIGURE 3 On-road vehicles: TxDOT Fleet Data Analysis, 1995.

duty trucks and heavy duty trucks with the sedans making up only about 12% of the fleet. Gasoline fueled vehicles outnumbered diesel fueled vehicles by a three-to-one margin. Most of the sedans and light-to-medium duty trucks are gasoline fueled. Figure 3 details the on-road fleet makeup.

Data from each of the 130 fueling locations was analyzed in detail. Types of fuel presently available at each location were compiled along with daily and weekly usage amounts. A delivery capacity analysis consisting of the number of pumps and associated nozzles provided an understanding for fuel delivery at each location. This data provided not only usage quantities but also a queue analysis of the pumps on a daily basis. It was determined that on average most vehicles travel approximately 50 miles (80.5 km) per day and use only 4 gallons (15.14 l) of fuel. Onsite storage capacity for each fuel type and refill service records provided a check and balance method for fuel usage in agreement 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).

Assessment of Available Alternative Fuel Technology

The available fuel infrastructure associated with any alternative fuel selection is important to understand. Consideration must be given to whether an alternative fuel chosen will significantly alter current operation with new refill and access requirement. The preferred refueling method may be fuel onsite for easy access and control from the outright purchase of refueling equipment to leasing option.

Alternative fuel technology is quickly outmoded. As was the large amount of older conversion equipment developed for vehicles prior to onboard computer circuitry, current conversion equipment is being designed to operate in conjunction to this circuitry for better performance vehicles with greater mileage and lower exhaust emission.

The ideal alternative fuel vehicle is still one produced by a major original equipment manufacturer (OEM) tested in accordance with governmental regulations and backed by the OEM warranty.

Performance of Life Cycle Cost/Benefit Analysis on All Potential Choices

After all the elements of the proposed alternative fuels program have been identified, it is important that they be used to prepare a life cycle cost/benefit analysis (LCCBA). The time value of money should be considered in the analysis. It is hoped that over the useful life of the involved equipment all of the benefits will offset all of the costs associated with converting the operation to run on alternative fuel. An example of one segment of LCCBA analysis which considers the tank size (and quantity) versus cost to refuel is shown in Figure 4.

The primary benefit contributor will be savings associated with a lower alternative fuel price. If the price of the alternative fuel is not substantially lower than the price of the fuel, it is replacing it may be very difficult to

CNG TANK SIZE vs Cost To Refuel

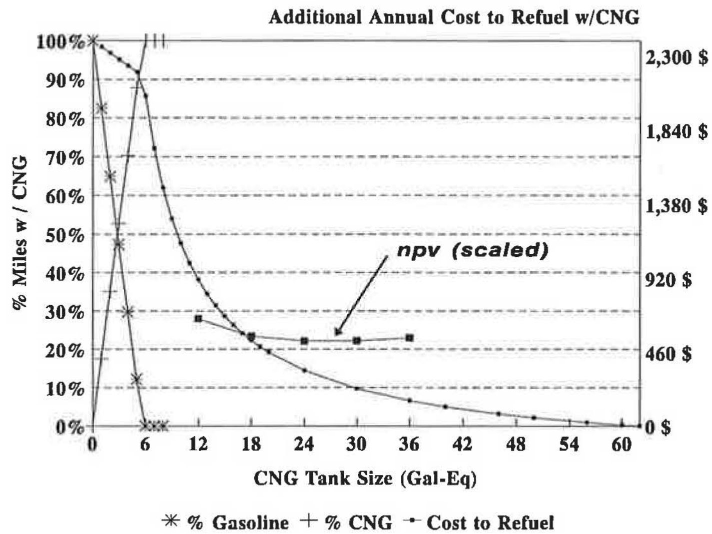

FIGURE 4 CNG tank size vs. cost to refuel: TxDOT Life Cycle Cost/Benefit Analysis Data, 1994.

show any payback over the expected useful life of the equipment. Figure 5 shows that the price spread between natural gas and gasoline may not be as large as expected and does not seem to shift significantly from one year to the next.

Although difficult to quantify, it is fair to include societal benefits resulting from the reduction in harmful effects of pollution on the environment. It is also fair where appropriate to examine possible benefits to the state/local economy.

Gainful Experience of Potential Choices

If vehicle conversion is elected, it is extremely important to know the vendor's reputation. Inspect prior year conversions and customer references. One valuable way to further personal understanding is to perform a pilot project aimed at conversion to a small vehicle number of alternative fuel(s) selected. This should allow through nominal cost an evaluation for both good and bad points inherent in each fuel. For onsite convenience, refill equipment may be leased. If funds allow, a research contract with a nearby university might gain insight to analysis of all relevant data through their manipulation.

To further departmental understanding of alternative fuel technologies, a series of demonstration projects were initiated in 1990. Twelve pickups were converted to run on LPG each carrying a 40-gallon (151.4 l) fuel tank. In addition, 19 light duty pickups and five sedans were converted to run on CNG. Each sedan carried five gallons-equivalent (18.9 l) while each pickup carried 10 gallons-equivalent (37.9 l).

A quick-fill CNG compressor station (built by Corken International, Oklahoma City) was installed at the Austin District Office. The station consisted of a 50 cfm (85 cmh) compressor and 200 gallons-equivalent (757 l) of stored compressed natural gas. A commercial slow-fill CNG compressor called FuelMaker® was also installed at several locations.

To assist in the conduct and analysis of these conversions the Department worked jointly with the University of Texas at Austin Center for Transportation Research. They developed an evaluation framework including economical, environmental, operational and technical strategies. Their research concluded that no TxDOT sites were deemed economical for CNG quick-fill compressor service. The decision matrix did not include societal benefits from cleaner air or state economical benefits.

Development of Sound Procurement Specifications

To purchase sound conversion equipment, it is necessary to have sound procurement specifications.

Gasoline vs Wellhead Natural Gas

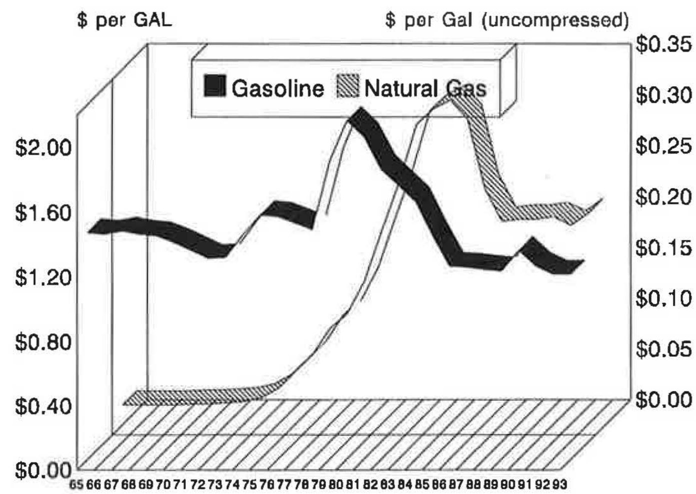

FIGURE 5 Gasoline vs. wellhead natural gas: Department of Energy 1993 Annual Energy Review

Natural Gas Fill Ratio in 10" x 50" Aluminum

Cylinder at End of 3,000 psia Charge

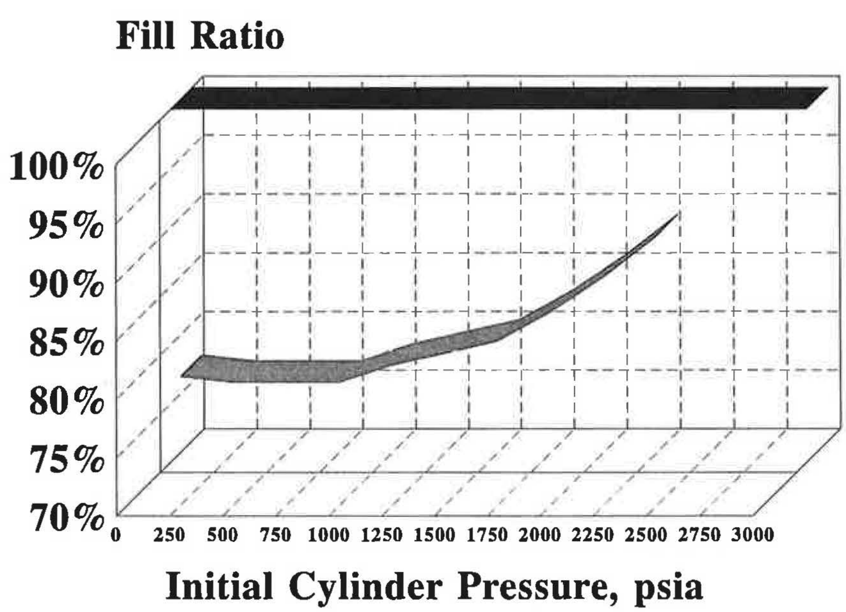

FIGURE 6 Natural gas fill ratio in 10" x 50" aluminum cylinder: Institute of Gas Technology; Storage Cylinder/Fueling Station Pressure Study, July 1993.

Several areas of concern, which left unspecified, could lead to poor fleet operation and performance. The conversion equipment should be approved by some regulatory entity (EPA, CARB, etc.) that has tested the equipment for both operation and safety. Life cycle tests should show that the equipment will perform over its expected useful life.

Sufficient fuel quantity for a full operational day should be designed into the vehicle. Consideration of the settled pressure effect for CNG fuel tanks should be taken into account. Figure 6 illustrates the fill ratios which result from fast-filling.

The converted vehicle should be setup on a dynamometer and the emissions tested before and after conversion to insure no degradation in power or quality of exhaust emissions. One potential weak link in an alternative fuel system is the electrical connectors used to attach it to the vehicle. These should be either OEM type connectors or the wires should be soldered directly to the vehicle wiring. An extended warranty should be a requirement within the conversion contract to afford as much protection as possible from early failure of poorly designed conversion equipment. Ensure that one party is ultimately responsible in the event of an impasse over the cause of equipment failure.

To ensure a reliable conversion, the Department has developed its own conversion specifications for gasoline fueled vehicles. These specifications require the conversion components be approved using EPA Memo-1A procedures and meet EPA standards.

Additional elements to the specification include the requirement for automatic fuel switch-over valves in CNG converted vehicles. This valve automatically switches fuel from CNG to gasoline when the CNG supply is depleted. Due to the almost instantaneous stalling that occurs when CNG is deplete, this device will be required for reasons of safety and driver acceptance.

The original equipment air filter must be kept whenever possible. Setup on a dynamometer is required also. The dyno ensures that converted engines maintain a horsepower rating of 85-100% after conversion. The Department is requiring ANSI/NGV1 (3,600 psi/248 bar) type refuel probes as industry standard. Emissions pre- and post-conversion are required.

Investigation of Different Conversion Technologies and Their Respective Exhaust Emissions

Many types of conversion technology are currently available and their performance as well as operation differs greatly. The preferred conversion system should have a complete closed loop (microprocessor controlled) feedback control mechanism capable of maintaining the air/fuel mixture to manufacturer specifications when operating on the alternative fuel. The system should have an adaptive-learn capability which can analyze and act upon the engine sensors and their dynamic real-time outputs. Operation on the alternative fuel should not adversely affect driveability or emissions. TxDOT is currently working with the University of Texas Department of Mechanical Engineering on a two-year emissions-based program called *The Texas Project*. Twelve conversion technologies and one hundred vehicles are being researched and tested with the purpose of monitoring emissions and vehicle performance.

LOGISTICAL DETERMINATION WITHIN THE DEPARTMENT

- Most of the 430 onsite refueling locations in the state have only 20-30 vehicles per site.
- Most vehicles travel approximately 50 miles (80 km) per day or less with a refill only once to twice per week.
- Tested CNG vehicles are averaging 5% less MPG (kml) and tested LPG vehicles are averaging 10% less MPG (kml).
- A 10 gallon-equivalent (37.9 l) supply of CNG should be adequate for most light-duty pickup applications.
- A five gallon-equivalent (18.9 l) supply of CNG may be inadequate for most sedan applications.

Department preliminary conclusions suggest that diesel aftermarket conversion technology is premature. No large manufacturers are presently offering alternative fuel CNG or LPG engines in the small size needed for diesel conversion.

Life cycle cost/benefit analysis for both CNG and LPG conversions show them not as cost effective for TxDOT operation. Only as the price for alternative fueled vehicles is reduced, which is anticipated with large scale production of new vehicles, will lifetime cost effectiveness be realized. It also has been determined that CNG through high cost of the stand alone CNG compressor fill station is not cost effective at small onsite refueling locations.

AREAS OF CONCERN

- *Gas inconsistency*: Delivery variances in purity and BTU content may occur, specify in the contract (CNG & LPG).
- *"Oil-in-gas" and "Water-in-gas"*: Fouled gas injectors and frozen fuel nozzles have occurred, TxDOT

considering SAE J1616 (SAE *Recommendation only* at this point).

- *Refueling infrastructure*: CNG infrastructure is underdeveloped in Texas, nozzle standardization must be implemented.
- *Proven technology*: Conversion of diesel engines to alternative fuel use has potential problems related to engine durability and acceptable operational performance.
- *Warranty*: Converted vehicles should be warranted for at least three years.
- *Insufficient gas supply*: Natural gas delivery has been curtailed to commercial businesses in Texas during severe cold spells.
- *Fuel price fluctuation*: The greatest cost denominator for using alternative fuel is the price differential between it and gasoline/diesel fuel, irregular price makes saving predictions risky.
- *Conversion cost*: Varies vendor to vendor, competitive bidding will help contain price.
- *Conversion kit compatibility*: Ability of conversion kits to meet On Board Diagnostics II (OBD-II) requirements.
- *Narrow Application*: Availability of EPA-Compliant conversion kits for a variety of applications.

SUMMARY

In a continued effort to meet the requirements of Senate Bill 740, the Department plans to purchase nearly 500 alternative fuel vehicles this year. More than 90% will be fueled by LPG while less than 10% will be fueled by CNG. Assignment strategy is based primarily on the availability of natural gas in various TxDOT locations with an emphasis on nonattainment areas. When natural gas is available, a CNG vehicle will be assigned. If natural gas is not available, LPG will be assigned. Currently, the Department is requesting waivers on all diesel engines until proven technology is available from the original equipment manufacturer.

In conclusion, Texas has become very proactive in environmental protection measures and will move toward more stringent clean air legislation for the future. At present, Texas Senate Bill 740 represents a challenge to a way of life which has been standard for decades. Many ideas and many ideals will have to change for alternative fuels to be the widespread fuel of choice in Texas.

LEARNING FROM ABROAD — WINTER MAINTENANCE PROGRAM

Leland D. Smithson
Iowa Department of Transportation

INTRODUCTION

The cost of winter maintenance in North America consumes a staggering amount of money, about $2 billion annually (1). These expenditures do not include the costs associated with corrosion, water quality degradation and other environmental impacts. Even a modest improvement in present snow and ice control procedures can produce substantial savings. Each State's economy and quality of life rely heavily on a reliable and safe highway transportation system, so any improvement in winter maintenance practices can help to enhance and fulfill those economic and mobility needs.

In recognition of the major annual investment made by state and local governments in snow and ice control, the need to advance the use of state-of-the-art technologies in this critical endeavor, and the fact that snow and ice control operations in the United States differ from those used in other countries, a Winter Maintenance Panel was organized and visited Japan and Europe to study the differences. The Panel was sponsored by the U.S. Department of Transportation's Federal Highway Administration's Office of International Outreach Programs, the American Association of State Highway and Transportation Officials, and the National Cooperative Highway Research Program of the Transportation Research Board. The Panel consisted of six U.S. managers responsible for snow and ice control operations from federal, state, county and municipal authorities. General topics of interest to the Panel members included winter maintenance equipment, anti-icing and de-icing operations, road weather information systems, weather forecasting services, public information systems, policy, roadway level of service criteria and environmental issues. The Panel visited Japanese and European officials at national and local governments, and toured field operations and research facilities.

Each area visited in Japan and Europe had very complex winter maintenance problems. Each country developed unique solutions to those problems that may have application here in the U.S. A Winter Maintenance Program involving federal, state and local governments has now been established in the United States where technologies imported from other industrialized nations and/or developed in the U.S. will soon be demonstrated, vigorously evaluated and acceptance tested in an operational setting against the state-of-the-art.

PARTNERING TO IMPROVE WINTER MAINTENANCE TECHNOLOGY

Partnering is an important part of creating and implementing new and innovative winter maintenance technology in Japan. An example of that partnering was demonstrated in the way the Japanese Government solved the following serious air pollution problem. Hokkaido, the northern island of Japan, receives more than 500 centimeters of snow each winter. This heavy snowfall combined with high traffic volumes team up to create difficult snow and ice control problems. Studded tires were introduced in Japan in 1962 to improve winter mobility. Before 1962 mobility was achieved by putting chains over summer tires. By the late 1970s nearly all drivers were using studded tires. These studs rapidly eroded the road surface, creating a heavy concentration of dust and contributing to an air pollution problem. To address this problem, the Japanese Ministry of Trade and Industry introduced a studless tire in 1982. The government partnered with private industry and heavily promoted studless tires by offering rebates on new studless tire purchases. The government also partnered with education by providing winter driving training courses to teach motorists how to use the new studless tires effectively. This partnering changed motorists driving and buying habits and resulted in very few studded tires being used today. The bottom line partnering benefits are that air quality today is greatly improved and Japanese motorists have good winter mobility.

The Hokkaido Development Bureau conducts quasi public/private ventures in the development of new construction and winter maintenance machinery. A next generation snowplow truck is currently under development. Manually performed operator tasks are being automated. These tasks include the setting of down pressure and blade angle for underbody plows and the height adjustments of a wing plow to clear roadside guardrail. The operator because of automated steering assistance does not feel lateral snowplow forces. On-board video cameras and in-cab displays provide the operator

with multiple angle observations of plowing operations in progress.

WINTER EQUIPMENT TECHNOLOGY

The Panel visited road maintenance facilities in Japan and Europe. Equipment, roads, bridges and facilities were of high quality and well maintained. Fuel taxes greater than two dollars per U.S. gallon and approximately 25 cents per kilometer tolls plus often a $1.50 terminal fee provide an excellent funding base for roadway construction and maintenance.

The Panel visited the equipment display at the Permanent International Association of Road Congresses (now World Road Association—PIARC) meeting in Seefeld, Austria. This was the largest display and demonstration of winter maintenance equipment in Europe. Snow blowers, plows, trucks, loaders and spreaders demonstrated advanced technology and increased capacity to that found in the U.S.

Since the price of salt in Japan and Europe averages about $250 per short ton, chemicals are used very sparingly. They always prewet salt or abrasives at the spinner with brine or liquid calcium chloride to reduce material loss and speed up the melting process. Hopper spreaders are designed with plastic storage tanks for liquids that tuck under the spreader's sloping sides. Most units have ground speed orientation or fifth wheel sensing for better spread rate accuracy.

Snow plows are usually heavier than U.S. plows, some have independent one meter sections that conform better to the pavement cross section or varying crown with blades made of metal, plastic or rubber. Some plows have foldout sections to increase plowing width. To reduce snow over spray and increase operator visibility, a canvas snowplow shield is mounted about 25 cm above the snowplow. This shield traps most of the over spray and forces it under the truck.

WINTER TRAFFIC MANAGEMENT SYSTEMS

Roadway weather information systems in Europe and Japan provide impressive amounts of information to both road maintenance operators and the motoring public. Typical climate sensors include ambient air and pavement temperature, wind speed and direction, humidity and road brine concentration. There are video cameras mounted along the roadside that provide a visual observation of road and weather conditions. The Hokkaido Development Bureau designed a prototype winter maintenance information vehicle that has a suite of sensors and visibility imagers on-board that provides a moving assessment of roadway and weather conditions. This vehicle also gathers information on pavement temperature and rolling wheel friction.

This information is brought to a central traffic management station via land line or radio datalink. Experienced traffic engineers and meteorologists are on the staff of these management centers. These centers can change the speed limit and information signs on a section of roadway remotely and selectively close or limit access to sections of the roadway. They can automatically call for emergency services. Information developed in these traffic management centers is distributed to the motoring public through extensive audio and video displays at rest areas and information sites.

IVHS FOR MOTORISTS

Japan utilizes advanced global positioning satellite (GPS) systems for tracking vehicles and reporting information to their management systems. Nearly all the government vehicles used to transport the Panel in Hokkaido had GPS and a television monitor that reported the vehicle's current position and direction of travel on a moving street grid background. Technology using Intermittent/Minimum Zone Mode Communication coupled with digital route maps allow motorists to be informed on-line and en-route of potential delays or hazards and offer alternative route planning.

PANEL RESEARCH AND TECHNOLOGY TRANSFER RECOMMENDATIONS

The Panel prepared a brief summary report with technology program and transfer recommendations at the end of the trip. The document served as the basis for the National Cooperative Highway Research Program (NCHRP) Research Results Digest Number 204 published in January 1995 (2). The NCHRP Digest summarizes findings and recommendations of the international tour and delineates the guidance found in the AASHTO Administrative Resolution that calls for the establishment of a Winter Maintenance Program (WMP). AASHTO's concept for the WMP is:

> *AASHTO subscribes to the concept that Member Departments, and appropriate agencies in the nation's counties and cities, should consider developing and adopting for their respective jurisdictions a system concept for snow and ice control on their highways, roads and streets, addressing the vehicle, the driver, and*

the equipment and practices for managing roadway and bridge snow and ice, and designed to assure that the best technologies in the world are properly and effectively used in the United States.
The goals for such a system concept should be to:
-sustain or improve levels of winter maintenance service with significant cost/benefit improvements;
-provide an enhanced level of environmental protection; and
-increase the safety of driving under winter conditions.(2)

The AASHTO Administrative Resolution recommended the use of funding under NCHRP Project 20-7 and the establishment of the AASHTO Winter Maintenance Policy Coordinating Committee to monitor and advise on a full program of winter maintenance activities delineated in the following tasks:

Task 1--Develop a comprehensive guide for establishing a systems approach to snow and ice control. This will probably be a guide manual or handbook designed to provide state and local agencies comprehensive guidelines for snow and ice control programs under applicable geographic and environmental conditions.

Task 2--Establish an AASHTO Snow and Ice Pooled Fund Cooperative Program (SICOP). The purpose of this fund would be to use pooled funds to underwrite the costs of testing snow and ice control technologies not now in use in the United States.(2)

ACCOMPLISHMENTS

Accomplishments at the writing of this paper, April 1996, are: the NCHRP fund has been established; a Winter Maintenance Policy Coordinating Committee consisting of members from AASHTO, the National Association of County Engineers (NACE) and the American Public Works Association (APWA), has been appointed and has met several times; and a national workshop (to address tasks one and two above) was held. Workshop participants developed a working outline and an action plan for preparing and publishing the comprehensive winter maintenance guide manual and developed recommendations for the administrative and operating concepts and procedures to be used in the establishment and operation of the SICOP program.

OTHER ACCOMPLISHMENTS BY THE PANEL

Panel members have published articles in trade magazines, written and presented technical papers at conferences and national workshops, and actively tested international snow and ice control products in their agencies since returning from the tour. This has resulted in some lower cost and less complicated products being implemented in snow and ice control operations. Examples of these lower cost products include: Iowa uses more than 200 snow plow shields (European idea) to increase operator visibility and increase radiator and windshield life (3); Kansas City, Missouri uses an endgate to cover the snow plow moldboard (Japanese idea) to retain snow spoil when plowing across intersections; Minnesota has tested and published the results of many snow and ice control innovations, foreign and domestic, as part of its operational research program (4); and many states are now using prewetting and liquid applications of ice control materials and making their own brine to support these operations (European, Japanese and United States research ideas).

These lower cost and less complicated ideas can be built and tested by individual states, but the more complicated and expensive products such as the rearward (one-lane) snow-conveying rotary snow plows or the improved winter maintenance management systems the Panel saw demonstrated in Japan and Europe will need the attention of the Winter Maintenance Program to fund and insure tests are carried out in a fair and credible manner.

REFERENCES

1. *NCHRP Synthesis of Highway Practice 207,* "Managing Roadway Snow and Ice Control Operations," Transportation Research Board, National Research Council, Washington, D.C., 1994.

2. *NCHRP Research Results Digest Number 204,* "Winter Maintenance Technology and Practices-Learning From Abroad," Transportation Research Board, National Research Council, Washington, D.C., January 1995.

3. Smithson, L., "Americans Can Learn a Lot from European, Japanese Snowfighters," *Roads & Bridges,* Vol. 33, No. 6, June 1995, pp. 30-32.

4. "Statewide Maintenance Operations Research Report," Minnesota Department of Transportation, St. Paul, December 1995.

MINNESOTA DEPARTMENT OF TRANSPORTATION /FINNISH NATIONAL ROAD ADMINISTRATION—MAINTENANCE TECHNOLOGY EXCHANGE PARTNERSHIP

Päivi K. Martikainen and John H. Scharffbillig
Minnesota Department of Transportation

ABSTRACT

The Minnesota Department of Transportation (Mn/DOT) and the Finnish National Road Administration (Finnra) conducted a maintenance worker exchange during the winter of 1995-96. The intent of this exchange was for both agencies to get detailed knowledge of each other's winter road maintenance operations, equipment and materials through hands-on involvement. The exchange program is of obvious benefit to both parties. Finnra has many equipment and operational innovations of interest to Mn/DOT. Some of the more interesting equipment innovations are automatic greasing systems for graders and other equipment, automated grader mold board control systems to obtain precise vertical and horizontal control, a floating system for grader attachments to obtain better control of the front plow, wings and blades, and employs various toothed blades and rubber slush cutting edges. From an operational perspective, Finnra's use of self-directed work teams, and the emphasis Finnra places on local managers and operators working toward reducing costs enables them to compete effectively with private industry.

Similarly, Finnra's exchange worker will return to Finland with new equipment, operation and training ideas for possible implementation. These include zero-velocity salt/sand spreading technology, fiber optic lighting for snow plows, mechanical icebusters, and carbide cutting edge technology. Operational items include the greater use of snow blowers, side wing plows and siping of truck tires for greater traction.

In summary, both agencies have found innovative and cost-effective ways to deliver their service to the road user. From this first worker exchange experience, Mn/DOT will examine similar opportunities with other agencies.

PROGRAM HISTORY

The Minnesota Department of Transportation (Mn/DOT) has a long history of partnering with other agencies in transportation related projects, especially in winter maintenance research. Mn/DOT also has facilitated various technology transfer and employee training programs throughout Minnesota and the US. As part of its Maintenance Technology Exchange Program, Mn/DOT sent John Scharffbillig, a Highway Maintenance Supervisor to work with Finnra for three months during the winter season of 1995-96. He was stationed at the Raisio Roadmaster Area on the southwestern coast of Finland. In turn, Mn/DOT hosted Marko Kolattu, a Senior Highway Maintenance Operator from Finnra for the same period. Marko was stationed in Mn/DOT's Nopeming Maintenance Subarea in District 1, Duluth, which borders Lake Superior. These locations are illustrated in Figure 1.

Finnra and Mn/DOT have a long history of cooperative efforts and personnel exchange dating back to the early 1970's. Finnra and Mn/DOT have an on-going joint research program with two active projects—Salt Usage Comparison Study and the Maintenance Technology Exchange Partnership.

PROGRAM GOALS

The purpose of the worker exchange was for each agency to get first-hand knowledge of the other's road maintenance (particularly winter maintenance) equipment, materials and methods of operation to improve their own related technologies through research, innovation, implementation, technology transfer and employee training. This knowledge was gathered by observing the host agency's field operations including actual hands-on involvement in those operations, and participating in the daily work activities according to a detailed work program approved by Mn/DOT and Finnra. The exchange also included visits to local maintenance equipment manufacturers to obtain the latest knowledge on the host country's designs and innovations.

Through this exchange, each agency received significant benefits. First, the exchange workers toured various maintenance areas giving field personnel a chance to learn from them and their reactions relating to the differences between the two agencies' maintenance operations. Following the exchange, each agency has had

FIGURE 1 Minnesota Department of Transportation–*partnering*–Finnish National Road Administration.

their exchange worker as a resource for field research and personnel training.

PROGRAM FUNDING

Both operators remained full-time employees of their own respective agencies throughout the three-month exchange period. Funding for the related costs was provided by each agency for their own operator. However, to limit the need for actual money transfers between agencies, an agreement was prepared to address the exchanging of costs and expenditures accumulated during the Program. In addition, a formal Partnership Agreement was signed to specify issues relating to liability in the case of an accident during the exchange involving motor vehicle/personal injury claims.

INNOVATIVE METHODS AND EQUIPMENT FROM FINLAND

John Scharffbillig's experience in Finland has shown that the Finnra uses innovations in equipment and methods that are of immediate interest to Mn/DOT, as explained in detail in his monthly reports (2, 3). A few of the more important ones are described in the following paragraphs.

Equipment

The principal working parts of the *automatic safeguard greasing system* are the air-operated piston type pump and lines to the grease fittings. This system works similar to a conventional grease gun. A spring pushing on a plunger maintains a constant pressure to the fittings. The system runs both on an automatic timer or via a manual switch. When the unit is started, a solenoid opens letting the air pump power the grease flow to the fittings. Warning lights on the system let the operator know when it is out of grease, clogged or other problems. Use of the safeguard greasing system has significantly reduced equipment maintenance costs in Finnra.

Automatic slopper control is used when doing final grading of a surface. It is set to the angle wanted and it automatically keeps the grader blade at the selected level and angle. This function is controlled by sensors mounted on the turntable and the body of the grader. When the grader goes up or down, this system makes the needed corrections automatically, instead of the operator having to guess at the modified setting.

Super Kellunta floating system is installed on Finnra graders to obtain better control of the snow removal attachments including front plow, side wing, main blade and rear drag blade. This system permits the attachments to be either fixed in place or floating with a capacity to add down pressure on the attachments when needed. The system allows the front plow to be angled up or down, sideways, etc. The grader controls are configured for grading with the main blade controlled to a finer degree than the other attachments.

The Finnra uses advanced *blade cutting edge technologies*. Included are the Olofsfors P-300 "Swiss Cheese" blade, carbide-tipped pin blades, rubber slush blades, and a quick-attach system to mount these cutting edges. The Swedish P-300 blade has proven effective in removing compacted snow and ice, and it leaves a grooved surface for detention of deicing chemical or brine. The adjustable rubber blade mounted behind the front plow or the underbody blade is widely used for the removal of soft snow and slush. This eliminates the need for more chemical to melt the snow or slush. The quick-attach mounting system for the various cutting edges is a unique and time saving innovation.

Mn/DOT has already tried two sets of the P-300 system. There is a big difference in the principal behind the operation of the P-300 blade compared with the standard Mn/DOT blades, specifically in the mounting angle. It is now expected that with John's practical experience, Mn/DOT will implement the use of this new cutting edge technology.

Operations

As for operational procedures there are many features that were highlighted in John's reports (2, 3). The local Roadmasters are very aware of operational costs and how

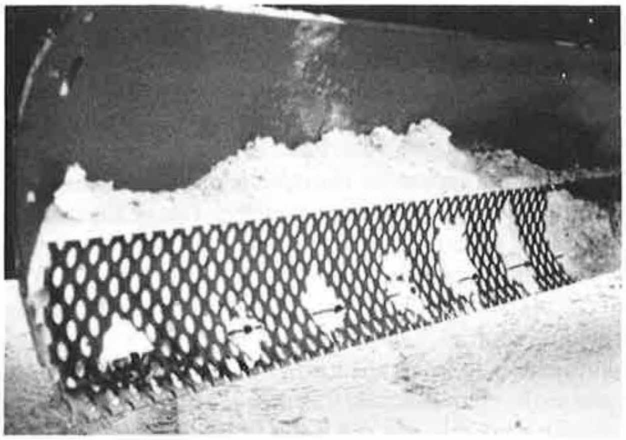

FIGURE 2 Olofsfors P-300 cutting edge, manufactured in Sweden.

FIGURE 3 Tyler zero-velocity spreader.

they compare with the private sector. With Finnra's drive to reduce operational costs, all the managers and workers are aware of activity costs and are attempting to reduce those costs further. Maintenance forces in Finland compete with private industry for maintenance work.

The Finnra maintenance workers operate in self-directed work teams. Each employee is asked to contribute ideas to improve maintenance and the maintenance program, and is aware of the goals for efficiency, and generally has a strong sense of personal responsibility to help meet these goals.

INNOVATIVE METHODS AND EQUIPMENT FROM MINNESOTA

During his stay in Minnesota, Marko Kolattu visited six of the fourteen maintenance areas within Mn/DOT and two county highway departments. He received the Minnesota Commercial Driver's License (CDL) and operated very diverse equipment. Marko concentrated on issues of concern to maintenance operators, and described his findings in monthly reports (4, 5). Marko's overall impression was good, and he was impressed with Mn/DOT's Traffic Management Center (TMC) in Minneapolis and the Highway Helper Program. He also was interested in the way Mn/DOT set up its operator training in units, covering topics such as hazardous materials, truck operating training, etc. and requiring its maintenance field personnel participate in the training in regular intervals.

At the end of Marko's visit he identified the zero-velocity spreader idea, fiber optic warning lights and some specific snow removal equipment as the things with most potential for successful implementation within Finnra. These ideas are briefly described below.

Zero-Velocity Spreader Concept

Zero-velocity spreading of salt and/or abrasives is a technology under development in Minnesota and several other states. This technology, as developed through the Tyler spreader in Minnesota, can substantially reduce salt and/or sand use and increase the maximum speed of the application. It is also considered that the technology has a direct application within Finnra's maintenance operations. Figure 3 illustrates a conventional Tyler zero-velocity spreader unit on a Mn/DOT truck.

Fiber Optic Warning Lights

Fiber optic warning lights are currently being field tested by Mn/DOT to provide better snowplow visibility in a snow cloud to the other road users. Initial tests show that the fiber optic lights effectively pierce the snow cloud and define the snow plow within. Marko Kolattu believes this innovation will soon be part of a standard maintenance vehicle package in Minnesota, and that it will be of great interest in Finnra.

Snow Removal Equipment

Other Mn/DOT maintenance operations equipment of interest to Finnra includes the grader-mounted Icebuster™ scarifier, illustrated in Figure 4. This is a rotating star wheel device for mechanically crushing hard packed snow and ice which are then removed with the grader blade. Also, Mn/DOT uses carbide cutting edges. Tests conducted a few years ago in Finland did not produce similar results due to a different blade operating and mounting technique. Marko Kolattu now expects that

FIGURE 4 Icebuster™ scarifier.

they can be effectively used in Finland with a small change in their operating technique.

In snow removal operations, Mn/DOT uses medium and large truck-mounted snow blowers to remove large drifts or snow banks. They are used also for clearing snow from intersections, interchange areas and under bridges. While not used in Finland, Marko believes that they would effectively complement Finnra's snow removal fleets. Mn/DOT also uses side wings to remove snow from both median and right shoulders. Mn/DOT keeps the shoulders clear of snow including the leveling of banks beyond the shoulder where Finnra does not typically clear. Again it was seen by Marko that opportunities exist within Finnra's operations for greater use of side wing plows.

An additional idea of interest was the siping of truck tires in the Duluth District. This is a method of closely spacing shallow transverse slices on the tire wearing surface to increase friction on slippery surfaces.

IMPLEMENTATION AND TRANSFER OF NEW TECHNOLOGY WITHIN MN/DOT (2, 3)

To improve the transfer of ideas to state and local maintenance personnel in Minnesota, John Scharffbillig will make presentations and participate in workshops conducted under the Minnesota Circuit Rider Technology Transfer Program for one year. This program is jointly sponsored by Mn/DOT, the University of Minnesota's Center for Transportation Studies, the Minnesota Local Road Research Board, and the Federal Highway Administration.(1)

In addition, selected innovations are to be subjects for further maintenance operations field research within Minnesota. The exchange worker is expected to be an active champion, sponsor, or principal investigator for Mn/DOT maintenance research projects developed and approved based on the technology brought from Finland. It is expected also that he will study, facilitate and work toward implementation of specific innovative Finnra operational knowledge and maintenance technologies or modifications to fit into Mn/DOT's scheme of maintenance operations.

A note of caution must be observed when planning to use any other agency's standard equipment. The Scandinavian blades for example use metric measurements for mounting hole spacing that differs from American or Mn/DOT dimensions. Typically, some modifications will be needed to adopt the other's equipment. For the P-300 cutting edges it was necessary for Mn/DOT to get separate mounting boards from the manufacturer. If an idea or innovation catches on, subsequent volume purchases could provide for adaptations to the other agency's requirements, and in Finland's case it should lead to international private sector partnerships.

CONCLUSION

Because of the Maintenance Technology Exchange Partnership, both agencies have found new, innovative and cost-effective ways to deliver maintenance products and services. Also, they have confirmed that most of their maintenance operations are managed and handled in an effective manner. Yet the most immediate result of the exchange for Minnesota is its input through technology transfer and training to maintenance field operations personnel and culture throughout the state.

To continue its active Maintenance Technology Exchange Program, Mn/DOT has approached other state agencies in the US and Canada, and some international transportation agencies to create further opportunities for maintenance technology exchange partnerships, based on the positive experience with the Finnra. Mn/DOT will be pursuing cooperative exchanges of personnel and equipment with interested agencies in the coming year.

REFERENCES

1. Martikainen, P., *Statewide Maintenance Operations Research Report, 1995,* Minnesota Department of Transportation, St. Paul, 1995, 95 pages.

2. Scharffbillig, J., *International Maintenance Technology Exchange Program: Monthly Report # 2,* Minnesota Department of Transportation, St. Paul, January 1996, 15 pages.

3. Scharffbillig, J., *International Maintenance Technology Exchange Program: Monthly Report # 3,* Minnesota Department of Transportation, St. Paul, February 1996, 14 pages.

4. Kolattu, M., *Finnra—Mn/DOT International Technology Exchange Program: Monthly Report # 1,* Finnish National Road Administration, Tampere, Finland, January 1996, 6 pages.

5. Kolattu, M., *Finnra—Mn/DOT International Technology Exchange Program: Monthly Report # 2,* Finnish National Road Administration, Tampere, Finland, January 1996, 3 pages.

SELF-DIRECTED HIGHWAY MAINTENANCE TEAMS: SUMMARY OF EXPERIENCES AND LESSONS LEARNED DURING THE FIRST FIVE YEARS 1990-1995

Roger McAniff, Strategic Performance Consulting, and
Dale Allen, Oregon Department of Transportation

This paper was extracted from the Summary, Conclusions and Recommendations chapter of a report by the authors published by the Oregon Department of Transportation (ODOT) in October 1995.

BACKGROUND

The purpose of this innovative program was to significantly reduce layers of management, create empowered self-directed maintenance teams, improve product service with fewer financial resources and make better use of human resources.

PROGRAM DESCRIPTION

On October 1, 1990, 22 section crews scattered across Central Oregon from the Washington border on the North to the California border on the South, reported to their maintenance stations. For the first time in the 75-year history of ODOT, there was no boss. That morning, each crew was expected to think, plan and produce results. Under the new culture, it was expected that employees would feel empowered to make decisions, feel better about their work and advance innovations. The goals and objectives of this program were to:

- Improve customer satisfaction of highway maintenance;
- Measure productivity increases through a performance measurement matrix and benchmarking system;
- Implement a pay for performance concept in state government;
- Strive for a proactive, high-morale work force; and
- Eliminate an entitlement work culture, and if necessary openly compete with the private sector.

LITERATURE REVIEW—KEY ISSUES RELATED TO TEAMS

Teams operate in a very complex and still poorly understood environment. There are no real manuals today for how to define and implement teams. There were even fewer resources when this program was started in 1990. The group was seen as the primary focus because individuals will resist changes that go against group standards or norms. Individuals will more readily accept changes when the group changes and the restraining forces are reduced. A person will naturally follow and accomplish goals that come from within while they may be highly resistant to goals set by others, unless they match their own internal goals.

We research the organization; start a change strategy; see how it is working; adapt to the new conditions; observe the results; and so on. Change is a dynamic process of trial and error that acknowledges the complexities of the change process and admits that we can not really predict the results of each change on a group of individuals or an organization of groups.

Commitment is a two way process - groups are more committed to individuals who help them attain group goals, and individuals are more committed to groups that help them satisfy personal needs. Interpersonal process has proved to be valuable for the personal growth of the participants, but of limited value in improving the ability of participants to be members of work groups. What makes group activities more successful is when the focus is on actual day to day work tasks. The group will focus on information gathering, problem solving and decision making functions. Avoid interpersonal issues except when there is clear evidence that such issues are hindering effective work performance.

Team building works when four conditions are met:

- Interdependence—the team is working on important problems in which each person has a stake. Team work is essential to success, not an ideology;
- Leadership—the boss wants to improve performance so strongly that he/she is willing to take the risk that initially the best decisions may not be made;
- Joint Decision—all members agree to participate; and
- Equal Influence—each person has a chance to influence the agenda.

Working with teams in the public sector is different than working with teams in the private sector in seven key ways:

- The dominant emotional tone in the public sector is fear;
- There are frequent crises of agreement in the public sector (groupthink);
- Loose coupling is prevalent in public sector systems;
- Politics and power are more persistent and insistent in the public sector;
- Confidentiality is more relaxed or less available in the public sector;
- Differentiation of high status and low status people is more pronounced in the public sector; and
- The press or media are much more a factor in change in the public sector. Public support for "risk taking" is normally lacking.

Companies with strong performance standards will usually have greater success with teams. By focusing on performance and team basics—as opposed to trying to become a team most small groups can deliver the performance results that require and produce team behavior.

LESSONS LEARNED DURING THE PROGRAM

Team Issues

Three key assumptions were made. 1) experienced maintenance crews and supervisors knew how to maintain highways and were the best decision-makers; 2) the area maintenance managers (AMMs) were capable of making technical decisions on required maintenance programs; and 3) AMMs and workers on crews were capable of dealing directly with the customers/public in their areas. All three assumptions turned out to be true.

Customer service and satisfaction was equal or better during the program. The self-directed highway maintenance teams each progressed in their own way and at their own pace. Personnel conflicts greatly slowed development. The maximum crew team size that appears to be able to effectively work together is 8 to 10 members without specially trained on-site facilitators. A few of the teams were very task oriented and had a long culture of high performance. These teams transitioned quickly and continued to perform well. An attitude of autonomy is necessary for effective self-direction. Intrinsic motivation appears to be a necessary ingredient for success. Task teams, that have specific and measurable performance goals, work better. The decision box for each team needs to be clearly defined and "handed off" as the team develops and is capable of making these decisions.

Process Issues

Disagreement among team members is natural and positive. Long-term, unresolved, personal conflict will stop a team from functioning effectively. The rapid implementation put teams immediately into a problem-solving mode and significantly challenged them to perform and actually solve real problems. The early in-house facilitators and the AMMs were the real strength of the immediate change. We would still launch the program as a single plan on a single date (rapid change), but we would do more planning and preparation work before the kick-off. The focus of the immediate change became the formation of teams. In hindsight, the focus should have been performance and using teams to accomplish that performance. The initial model and process was a beginning to get started and unfreeze the existing system - in that context it was very successful. We recommend that the change should not be a pilot but be implemented as a permanent, long-term change. Committed managers can change and adapt these new rules and models.

Management Issues

An ongoing in-house leadership academy that would nurture common understanding of leadership behavior at ODOT would have been extremely useful. A revised concept of shared leadership, each member of the crew doing what they are good at and each person leading those areas that are their unique talents, was successfully introduced later. This approach reinforced that while all crew team members are equal, they are not the same.

Self-directed teams cannot perform under autocratic managers or managers unable to accept some risk. Several managers could not "walk their talk" and had to be removed or removed themselves from the program. Many otherwise qualified people could not let go of control. They just did not fit well in this type of environment. Managers needed to serve a dual role. On the one hand, they were leaders encouraging their teams to use good team process, make good decisions and achieve high performance. On the other hand, they still needed to be managers of the workers defining and dealing with problems in behavior, performance and all the rules that are part of being in a state organization.

The lack of monetary incentives for becoming high performance self-directed teams is seen as one of the key issues that may block the program from reaching its full potential. It is highly recommended that other programs of this type build in team based incentive pay for successful teams. Clear, simple, highly visible performance

measures are highly recommended for organizations undertaking self-directed team programs. In retrospect, the self-managed approach went too far too fast and was not appropriate for a state agency in a union environment. Self-directed teams with significant management input is seen as the right balance. We recommend that other organizations clearly define the administrative/paperwork aspects of the program as part of the planning and provide sufficient administrative support to the program so that other resources will not be reduced. Initially, this may require increased staff to handle all the changes in process.

An informal team of the Region Manager and the seven AMMs actually was a key success factor of the program. We strongly recommend that the key managers (in this case the AMMs) and a top manger totally committed to the program form a permanent team to implement and guide the program. This oversight support would need to remain for at least five years to make the program effective.

External Support

Visible public support by groups such as the Ford Foundation, Western Association of State Highway and Transportation Officials, and the American Public Work Association was critical during the difficult transition.

MINNESOTA DEPARTMENT OF TRANSPORTATION'S MAINTENANCE OPERATIONS RESEARCH PROGRAM

Päivi K. Martikainen and Paul F. Keranen
Minnesota Department of Transportation

ABSTRACT

Minnesota Department of Transportation (Mn/DOT) has supported an active Maintenance Operations Research Program since 1990. This program seeks to develop the most effective maintenance procedures, materials and equipment, and focuses on "on-the-road" or applied research evaluating projects under actual field conditions with state personnel, academia, private vendors and various combinations conducting the research.

From local and state perspective, Mn/DOT's Circuit Rider Technology Transfer Program has proven to be a very effective way to transfer road maintenance technology internally and between the different interests. This program is a partnership between Mn/DOT, University of Minnesota, Minnesota Local Road Research Board and Federal Highway Administration. Three part-time facilitators conduct interactive maintenance-related workshops at maintenance facilities throughout Minnesota and gather technology developed in the field to share it with other local and state workers.

Typical of the program's summer-related research is evaluating new technology for repairing cracks and potholes such as slurry seal patching and micro surfacing. Other research focuses on issues such as vegetation growth control to reduce mowing needs. Winter maintenance research includes such issues as de-icing, anti-icing, continuous friction measuring, zero-velocity spreading and automated bridge deicing systems. Maintenance management research includes the development of a variety of systems such as a statewide maintenance management system, pavement marking systems, thermal mapping, weather reporting, bar-coding, automated call-out systems and automated route planning systems.

This research program is considered to have provided a substantial return on research program investment. Savings in salt and sand use alone with the newly implemented deicing systems practically offset the annual cost of the program.

PROGRAM HISTORY

The Minnesota Department of Transportation's (Mn/DOT) Office of Maintenance has supported a Maintenance Operations Research Program since 1990. It is managed by the Maintenance Operations Research Engineer (MORE) with program oversight by the Area Maintenance Engineers who finance the research program directly from their operating fund. The new technology and methods for maintenance operations created through the program are seen as a way to optimize resources. This is seen necessary since despite the shrinking work force and budget, the traveling public continues to expect the same or even a better level of service. Having such an operating unit within Mn/DOT that both funds and administers its own applied research initiative is considered unique both nationally and internationally.

PROGRAM GOALS

The goal of the Maintenance Operations Research Program is to involve maintenance areas throughout the state in research projects that address all elements of maintenance operations including snow and ice control technology, pavement, roadside and bridge maintenance, buildings & grounds maintenance, work zone safety as well as technology transfer. The research program focuses on "on-the-road" or applied research taking developed methods, materials, products or prototypes out on the road and field testing them in a structured manner under actual environmental, weather, traffic and other conditions. The program seeks to develop the most effective maintenance procedures, materials, and equipment and to build on research conducted or supported by other agencies and states, the Federal Highway Administration (FHWA), academia, other countries, and private industry.

Research is conducted by different investigating entities depending on the nature and complexity of a particular project. Principal investigators include state maintenance personnel at the truck stations, and university faculty as well as private vendors working alone or in concert with Mn/DOT's maintenance and/or materials research laboratory personnel. The object is for the state or individual maintenance areas to implement successful processes and methods, as well as to acquire and use any equipment or material developed through this research. One of the key thrusts of the program's research efforts is to move from reactive to preventive maintenance.

TECHNOLOGY TRANSFER

An important aspect of the program is to transfer the new technology to potential users once it's developed. Methods used to facilitate technology transfer to implement good ideas and new innovations in equipment, materials, and methods include publications such as the Annual Research Reports [1, 2, 3], One-Pagers [4], video tapes, as well as the technology fair held in conjunction with the annual statewide rodeo. Also, presentations by project sponsors and MORE staff are given regularly at various meetings and conferences, such as in the first annual Maintenance Research Conference held in April 1996.

Circuit Rider Technology Transfer Program

Minnesota's Circuit Rider Technology Transfer Program is currently being coordinated through the Maintenance Operations Research Unit while being a partnership between the Mn/DOT, the University of Minnesota's Center for Transportation Studies (CTS), the Minnesota Local Road Research Board (LRRB) and the FHWA. As of March 1996 there are three part-time facilitators working with the Circuit Rider Program making presentations and putting together interactive workshops throughout the state. They visit both Mn/DOT field offices as well as local government agencies exchanging highway maintenance technology between state maintenance workers and between the state and local units of government, "downloading" research results in order to get the best return for investment made towards research in Mn/DOT and elsewhere.

This quickly expanding program involves field visits on a scheduled or as-called basis to Mn/DOT's maintenance areas and, with funding provided by the Minnesota Local Road Research Board, to county and city maintenance facilities. These visits are intended to bring new technology to the field, gather similar information from the field, and exchange this information between the maintenance units as well as between the various units of government. This program has helped Mn/DOT fulfill its goal of facilitating the transfer of FHWA, Transportation Research Board (TRB) and other national and international transportation technology to local government agencies in Minnesota. To link the program to something that its customers could identify and easier visualize, Mn/DOT provided a refurbished van with the Circuit Rider partnership logo painted on it, as illustrated in Figure 1. This van, along with a trailer donated by the FHWA, is used for transporting the program-related equipment and displays from site to site.

The specific program site activity is highlighted by a periodically changed photo display of about thirty 11"x 14" photos that are changed as new highway maintenance innovations are discovered. The program also includes an interactive compact disc (CDI) training system provided by the Center for Transportation Studies, currently featuring sessions on winter maintenance and work zone safety. It also includes extensive literature provided by the FHWA, Mn/DOT and others as well as demonstrations of selected work zone safety devices and other equipment innovations. A trained facilitator with a highway maintenance background discusses new innovations presented in the photo display and/or presents a structured training workshop on a given topic such as snow & ice control, use of prewetting, pavement rehabilitation, etc. The facilitator will also explain and distribute displayed literature, encourage submission of innovative ideas from the participants and document innovations observed at the visited site. An example of a Circuit Rider workshop presentation is shown in Figure 2.

During 1995, the program's first year of operation, the Circuit Rider visited 46 locations including visits to Mn/DOT, county and municipal facilities with additional visits to Canada and eastern US states. The greatest accomplishments were that training was brought to the maintenance personnel at their place of work for reduced cost and increased accessibility, and that many local innovations were discovered, documented, and shared with other governmental agencies. In addition, barriers between all levels of government were lowered, thereby increasing information exchange and encouraging financially beneficial partnerships, such as sharing equipment and facilities.

During 1996, 50 to 60 scheduled workshops are planned to local government facilities within Minnesota. This training will be provided by Mn/DOT Circuit Rider facilitators, coordinated and advertised by the CTS, and funded by the Minnesota LRRB. In addition to these site visits, similar workshops will be scheduled to Mn/DOT

FIGURE 1 Circuit rider van.

FIGURE 2 An example of a circuit rider workshop presentation.

facilities. By coordinating the Circuit Rider Program through a formal partnership, the workshops can be scheduled to reduce duplication and to increase efficiency benefiting all partners since all neighboring Mn/DOT and local government agencies are invited to attend any given workshop despite the location of the facility.

INTERNATIONAL ACTIVITIES

The Maintenance Operations Research Unit actively supports Mn/DOT's leading role in maintenance research. Part of this activity is Mn/DOT's outreach to several countries to obtain benchmark on their winter maintenance and other technologies. Continuous cooperative research coordination is being maintained with several Canadian provinces, Sweden, Norway, Finland and Japan. Still other contacts have been made with the Republic of Korea, Australia and several European countries. Some of the current active joint research projects include a continuous friction measurement evaluation project with the Norwegian Public Roads Administration, testing of Swedish cutting edges, as well as a salt usage comparison study and a maintenance worker exchange with the Finnish National Road Administration.

RESEARCH PROJECT FUNDING

The annual base budget committed to maintenance operations research is $750,000. Additional funding is periodically received for specific research projects from other research bodies such as the FHWA and Minnesota LRRB. A breakdown of Maintenance Operations Research Program funding for Fiscal Year 1995 (July 1, 1994 to June 30, 1995) by program category is shown in Figure 3.

The program involves large research projects which may have funding approved for over two or more fiscal years, as well as spontaneous "skunk works" type projects costing less than $12,000. Research proposals with funding requests of more than $12,000 are considered for approval by the Area Maintenance Engineers' New Technology Research and Equipment Committee (NTREC), whereas the MORE has authority to approve projects costing up to $12,000. The NTREC Committee typically meets quarterly to consider the larger project proposals submitted to the MORE.

To help manage the Maintenance Operations Research Program's annual budget, funding approvals and actual payments, as well as other data related to individual research projects, a project tracking system has been designed and is in place. The project tracking system provides easy access to Mn/DOT users who are able to view summary research information on on-going and historical projects, as well as to print out completed field test reports. The application is programmed on Paradox 5.0 for Windows, and is part of a statewide effort of linking various research databases together in order for Minnesota to be able to provide a better and more up-to-date service to transportation research professionals.

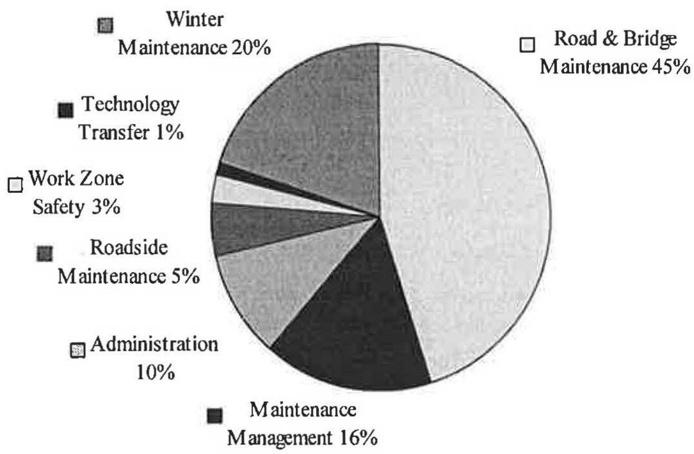

FIGURE 3 Maintenance Operations Research Program: Expenditures in Fiscal Year, 1995 [3].

CURRENT RESEARCH PROJECTS

Individual Maintenance Operations Research Program project report summaries including photos, sketches and text to describe selected projects, and their intended or expected outcomes, with the contact persons' phone numbers, can be found in Annual Statewide Maintenance Research Reports for years 1993, 1994 and 1995 [1, 2, 3]. The latest Annual Report 1995 [3] also contains a listing of smaller research projects underway in 1995, a listing of new projects approved for funding but not yet started, and a complete listing of maintenance research projects prior to 1995.

Roadside Maintenance

As unwanted weeds are treated it is necessary to use different herbicides to obtain maximum control of unwanted vegetation. To accomplish this, four automated sprayer prototypes were designed and evaluated. Other related research projects included weedmats, a remote slope mower, and biological control of Canada Thistle, etc.

Winter Maintenance

Mn/DOT's winter maintenance research focuses on maintaining roadway friction and a high level of safety while reducing salt and sand use, minimizing impacts on the roadside environment and minimizing corrosion [5]. Currently research is being conducted on integrated tailgates (as pictured in Figure 4.), improved snow plows and cutting edges, maintenance concept vehicle, vehicle (snow plow) conspicuity studies, snow fence evaluation, and continuous friction measurement, etc. Special effort has been put toward research relating to deicing and anti-icing methods, prewetting using salt brine and other chemicals, salt brine mixing systems, zero-velocity spreader concept, automated bridge de-icing systems, etc. Out of a total of over 800 trucks involved in snow removal, approximately 345 of them were operational with prewetting units by the end of the winter season 1995-1996.

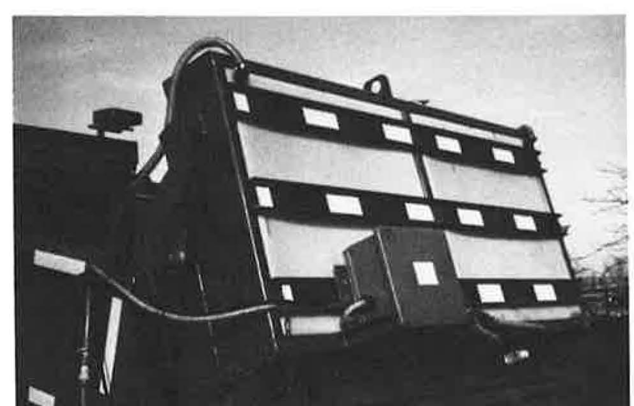

FIGURE 4 Reed integrated tailgate.

Road & Bridge Maintenance

Providing a smooth pavement for safe and efficient travel is one of the most important aspects of Mn/DOT's responsibilities. A Mn/DOT Statewide Smooth Pavement Task Force has been very active in addressing the issue of providing smoother, longer-lasting pavement surfaces. While the original focus of the Task Force was to eliminate potholes, current research projects include issues relating to slurry sealing, rough patching, crack sealing, micro surfacing, etc. Experiments are being conducted in the winter and the summer months, trying to find the most efficient and economical patching and crack sealing methods in both cold and hot climates.

Maintenance Management

Mn/DOT is in the process of developing its maintenance business planning products and services, as well as various aspects of a uniform statewide operations management system, including timesheet management system, and a pavement marking management system. Other on-going research projects relate to road weather information systems, thermal mapping, pavement condition and weather reporting, interactive travel information system, automated call-out system, bar-coding, paperless field data collection, automated route planning, etc.

CONCLUSION

Originally it was expected that the Maintenance Operations Research Program would be in place for a few years during which the individual Mn/DOT Districts would form their own processes for conducting maintenance operations research independently. The program has to some extent been able to help in achieving this goal, yet a need for a central body for administering statewide, national and international maintenance research activities has been realized. The Maintenance Operations Research Program will therefore continue to promote the importance of researching new innovative methods for preventive maintenance, and to ensure active two-way technology transfer through the Minnesota Circuit Rider Program.

REFERENCES

1. Barnes, M., and L. Impola, *Statewide Maintenance Operations Research Report: 1993,* Minnesota Department of Transportation, St. Paul, 1993, 44 pages.

2. Martikainen, P., *Statewide Maintenance Operations Research Report: 1994,* Minnesota Department of Transportation, St. Paul, 1994, 66 pages.

3. Martikainen, P., *Statewide Maintenance Operations Research Report: 1995,* Minnesota Department of Transportation, St. Paul, 1995, 95 pages.

4. Ehrisman, K., *Maintenance Research One-Pagers: Numbers 1 through 8,* Minnesota Department of Transportation, St. Paul, 1993-1996.

5. Keranen, P., *Winter Maintenance Research in Minnesota: A Nationally Recognized Program,* PIARC 1994 International Winter Road Congress, Seefeld Austria, March 21, 1994, 11 pages.

PERFORMANCE MEASUREMENT

Steven J. Wilcox
New York State Department of Transportation

ABSTRACT

Transportation maintenance organizations have collected data for some time, but rarely has that data been linked to the strategic interests, or management information needs of the leadership or management. Frequently that is due to the lack of clarity of what those interests are, making it impossible to align the organization to satisfy them. Performance measurement in New York State's Transportation Maintenance Division is an attempt to create a comprehensive and strategic framework for management. The framework begins to clarify the organization's mission, services that support that mission, and the characteristics of the service delivery process necessary for success.

Particularly important for agencies interested in exploring the idea of organizing around public service is to begin to define service expectations from the perspective of customers. By linking budgets and the quality assurance systems to customers, service priorities and levels can begin to be established cooperatively. Only then can meaningful performance measures be developed for the organization's various roles and responsibilities, that separate success from failure, from the standpoint of the people being served.

WHY MEASURE PERFORMANCE?

The process of organizing to measure the performance of an entire agency or some subdivision at that agency is arguably the most important element in results-oriented management. This involves examining why the organization exists, clarifying and reaffirming its purpose, and determining whether it is objectively meeting that mission as simply and elegantly as possible.

Implicit in defining an organization's purpose is understanding who it serves. Consideration must also be given to those characteristics processed by the organization and its services in satisfying the need of the user of these services, and in maintaining a healthy, effective organization.

Armed with the knowledge of why and for whom the organization exists, leaders can then determine exactly what services it provides that fulfill its mission, and then the processes for delivering those services. Assessing the service delivery processes, and any other processes providing direct support, will distinguish value-creating parts of the organization from others that no longer directly or indirectly serve the organization's purposes.

At this point questions of why, what, how and for whom have been answered, and that knowledge can be used in the development of strategy, priorities and goals. Once it is clear how the organization fits together and what the roles and responsibilities are for its strategic, tactical and operational levels, one can begin to measure the organization's capacity, behavior and health. Having an organization that is well-aligned in support of its mission, and where expectations and roles are clear, performance measurements can be set up to find how well the mission is being accomplished, to show that it continues to stretch its capacity, and that through its people, the vision of demonstrably better public service can be realized.

BACKGROUND

In 1993, the Transportation Maintenance Division of the New York State Department of Transportation began an effort to improve management effectiveness. A literature search suggested several forces driving organizational improvement efforts - among these are total quality management, reengineering, reinventing government, ISO 9000, and performance management.

These performance improvement approaches were studied to learn which aspects could benefit a public-sector, service-based organization like the Transportation Maintenance Program. Relevant concepts began to be sewn together and tailored in a manner that appeared most sensible for the program's circumstances. The ultimate goal that we refer to as *Performance Management* was to create a mission-driven, comprehensive, and well-aligned of management system.

As managers of the Department and Maintenance Program changed, so did the scope, priorities, and support for managing its performance. Though these changes have created "roller-coaster" effects and stalled application of the system, they have also provided the opportunities to clarify important precepts -- such as consistent leadership

support, and clarification of roles within the management hierarchy -- necessary for the successful implementation of an approach to management that significantly departs from the more comfortable circumstances engendered in the traditional command and control bureaucracy.

The original implementation plan consisted of a top-down statewide approach. The intent of this was to align the organization with a consistent statewide mission and strategy, and to gain management support before application to use at the next level down into the organization. As leadership changed, so did direction. A pilot based in the Hornell region in southwestern New York was chosen, based at the operational (working) level of the organization. The benefit of this change has been to work through several iterations of performance measures to obtain a set that operational managers find useful and relevant, and to develop graphical methods for expressing them. The weakness of this approach has been that without agreed-upon purpose, strategy, tactics, or key result areas supported by the leadership there is only an assumed direction to align the system to. Managers also are not being held accountable for measuring their performance causing it to be developed and used on a time-available basis. This results in performance measures being "nice to know," but not "necessary to use." New leaders are currently evaluating a return to the original approach.

A COMPREHENSIVE APPROACH TO PERFORMANCE MANAGEMENT

From the late 1980's, government agencies across the country, at every level, have been reevaluating how they deliver service to the public. Many government organizations across the country have produced radical improvements in the efficiency and effectiveness of their service delivery. Our intent has been to benchmark those agencies in various aspects of organizational transformation, and sew them together into a purposeful, comprehensive, and complementary system of management. The pieces viewed as critical to a comprehensive performance management system include: performance measurement, quality assurance, a service delivery system, and performance budgeting. These pieces needed much integration and overlap, as well as, the development of supporting pieces, such as a clear mission; service definitions; customer-oriented outcomes; key result areas; process management; clarification of strategic, tactical, and operational roles; and balanced, continuous improvement.

The models that we attempted to integrate included: Oregon DOT's Performance Measures [1], concepts of variation and continuous improvement from Total Quality Management [2], Texas State Government's Strategic Budgeting System [3], ISO 9000 Quality Assurance System Standards [4], and the key result areas from the Balanced Scorecard described by Robert S. Kaplan and David P. Norton in a series of Harvard Business Review articles.[5]

ORGANIZING FOR MEASUREMENT: PURPOSE, PROCESS AND PEOPLE

To measure performance anywhere in the organization a framework must be established clarifying 1) what results the organization is aligning to achieve, 2) why those results and with what priority, 3) how the various parts of the organization work together to achieve those results, and 4) the roles of the various levels of management in steering the organization to those ends.

Purpose

In the course of maintaining highways the organization does a lot of "stuff" -- pavement stuff, bridge stuff, roadside stuff, and snow and ice stuff. Establishing a mission, the answer to the question of *why* the organization exists, replaces "stuff" with purpose. The Transportation Maintenance Program has established four fundamental reasons why we do stuff: *Mobility, Appearance, Preservation or Safety* ("MAPS" for short, making it easy to remember). Following definition of the four fundamental purposes of the organization it was possible to survey management, asking for each of the roughly 100 direct tasks performed by maintenance workers, which of the four purposes was being met by doing that task.

The survey revealed eleven natural groups of activities defining the services that the program delivers to meet our mission. The services are defined by the feature being maintained, and what maintenance purpose. These services are: Winter Mobility, Mobility Restoration, Traffic Guidance and Control, Roadside Appearance, Rest Area Appearance, Pavement Preservation, Bridge Preservation, Pavement Safety, Bridge Safety, Roadside Safety, and Safety Appurtenances.

Outcome expectations can then be set and budgeted for these services. For example, Roadside Appearance is a service provided primarily to maintain an attractive roadside. The maintenance program performs four tasks to that end: mowing, litter collection, landscape maintenance, and removing dead animals, debris and encroachments. Statewide task history from our management information system details the historic costs and effort put into this service. If program managers want

to negotiate increased funds for a higher service level, a set of expected outcomes can be defined in terms of grass, trash, and carcasses. Administrative and overhead costs are included in the service cost making the cost a bottom-line price. The alignment with the mission also becomes clear. The purpose of litter-collection, for example, is improved appearance of the roadside, satisfying the overall mission of managing the highway's appearance.

Process

This answers the question of how the organization is put together, so that the desired results are produced as efficiently and effectively as possible. It orients the organization toward work flow and away from the static structural hierarchy.

Process flowcharting clarifies the steps necessary to successfully deliver a service. Receiving a service with the desired characteristics is all that the public cares about (characteristics include quality, cost, timeliness, etc.). Poor process design can generate inefficiency, high cost, and poor quality which are why so many organizations are undergoing process reengineering.

Process flowcharting also can serve to separate line functions from support functions. An important point to recognize here is that support functions are only as successful as their ability to supply the line function-they must be measured against those ends. For example, the Equipment Management function supports the Transportation Maintenance function and must be measured as if they supplied road salt, consultant service, or photocopier repair. All too often, support functions are measured as ends in themselves. Using the Equipment Management example, they could, through the type of equipment that is supplied, result in the line's work being determined by the support group, and not by the strategic service priorities. So rather than measure cost per vehicle maintained, it is more sensible to measure, for example, equipment cost per acre mowed demonstrating their impact on mission fulfillment. They would be fulfilling their unique purpose of maintaining equipment, but without a link to the line's mission, there is no guarantee that the equipment necessary is available to the line to meet expected service levels.

It is important to remember that the practice of continuous improvement that is fundamental to Total Quality Management (TQM) assumes that the processes being improved are already well designed. Further, strong bureaucratic structures that have been common in the public sector were designed to maintain the status quo - in an effort to control poor performance, they also discourage doing anything differently even if it is an improvement. Hierarchical approval systems discourage innovation and improvement by requiring approvals through lengthy and document laden justification processes. This is why many organizations are leaving the bureaucratic machine model with its roots in Frederick Taylor's scientific management model and are moving to a Japanese style values-based normative-control model.

People

For persons or groups to be effective, their roles and expectations must be absolutely clear. Roles are strategic, tactical, or operational. All three are critical, but all three are separate. Roles can become confused, particularly in organizations with poorly conceived decentralization or empowerment.

The strategic role involves those in the organization in a position to set a course. Typically, this is the senior executive management team. It is crucial that those with strategic responsibilities be connected to the market being served by the organization. For a public transportation maintenance organization, that market consists of 1) system users, 2) transportation interest groups, 3) politicians, and 4) agencies whose interests involve transportation. The primary responsibility of strategic management is to clearly understand where the organization needs to go, and to develop strategies, set priorities, and establish policies consistent with that direction.

The tactical role translates strategy into a form that can be carried out. This requires ability to assess organizational capacity to achieve strategic outcomes, plan and deploy resources, and perform the quality assurance function to determine the effectiveness of various tactics. Typically, this includes central office program managers and regional functional group directors.

The operational role delivers the work that fulfills the organization's mission in terms of the priorities of the organization. Those priorities and service quality requirements must be clear and supported to do this in a manner that aligns with the strategic priorities of the organization.

CUSTOMER REQUIREMENTS, QUALITY ASSURANCE AND MISSION-BASED BUDGETING

Customer Requirements

Public service is the essence of what government agencies provide, but only exceptional agencies are organized from a service perspective, and very few have an institutional

connection with the public. The greatest obstacles to overcome in reinventing the culture of public agencies are 1) serving the budget, 2) serving the structure, and 3) serving the boss.

For a true public-service orientation, organizations must be clear what services they provide to the public to fulfill their missions, ask the public what they want from those services, and also ask how much they are willing to pay. With that knowledge, agency leaders can then look into their organizations to deliver those services.

The widening division between government and the people is a consequence of government's lack of dialogue with those they serve. It is arrogant for a program administrators to assume they know what their customers want better than the customers themselves. Inevitably, tactical program managers get caught up in providing elegant, high-tech solutions to problems (and non-problems) because frequently the only formal dialog with the external citizenry is with the consultants or vendors.

Customer focus groups, customer councils, perception surveys, and town meetings are options that leaders have available to understand expectations of their constituencies. It is difficult to engage the public if the organization has not clarified what services it provides to fulfill its mission.

To understand services, it is important to know more than what is being serviced (pavement, bridge, roadside) but also why and to what ends, that services are aimed (mobility, preservation, safety, appearance). If you ask someone what is expected from the roadside he might ask, "The roadside *what*?" If you ask about roadside *appearance* or roadside *safety* you then have the basis for an exchange. Services are linked directly to tasks, and as a starting point the organization's task history can be used to learn what the average annual direct and bottom line costs, and labor commitment have been required for each service. Roadside appearance consists of mowing, litter pick-up, removal of dead animal/debris, and landscaping maintenance. Roadside safety consists of tree and brush removal, slope maintenance, and chemical weed control (of vegetation growing along guide rail). (It is unmanageable to define results for 100 different maintenance tasks and the permutations of why each is done.)

Defining broad categories reduces these to eleven services that have a mission-based organizing principles and results. This also provides overall outcome expectations for front-line managers and supervisors without tying their hands with individual task requirements. Roadside-appearance outcomes can be tailored at the local level to local conditions. Perhaps a rural area needs to place increased emphasis on mowing and dead-animal removal, while an urban area would focus more on litter pick-up and maintaining landscaping plantings. Both approaches are aimed at a pleasing roadside appearance.

Tailoring these approaches to public expectations completes the picture because a clear (rather than a guessed-at), organizational expectation is being met. Measuring organizational performance in delivering on public expectations fulfills the other half of the equation of what (paraphrasing the philosopher Robert Nozick) creates a sense of importance in human beings - doing something that counts, and having someone appreciate (by accounting for the fact) that it was done. Civil servants must know that their work contributes positively to society (by fulfilling a mission), and, favorably or unfavorably, that it is noticed (by being measured). People would rather know that they are doing a poor job than be ignored, unless there is no perceived relevance to their work.

This accounting through performance measures must consider both the level of performance relative to the organization's capacity, and the quality of service delivery. Capacity issues tend toward measures of efficient uses of fiscal and human resources, while quality issues are oriented toward the customer's satisfaction with service, developing internal human resource quality, and assuring the technical quality of the service being delivered.

Quality Assurance

The international standard for quality assurance systems is the International Standards Organization's 9000 Series (routinely referred to as ISO 9000). The quality assurance system is under development and uses the *framework* established in the 12-step 9003 Standards -a model for quality assurance in final inspection and test.

ISO 9003 was chosen over 9001 and 9002, which manage quality throughout the production and installation process (9001 begins as early as design and development), based on the nature of maintenance activities being well defined in their design, and the complexities of managing quality continuously for an array of 100 discrete maintenance activities. As the organization becomes more results-oriented, statistical sampling of the quality of services that have been delivered will require operational managers to continuously control work quality.

The precepts established for the quality assurance system are as follows: use the framework of ISO 9003 (that the aim is not certification, but consideration of all elements necessary for a comprehensive quality system), develop customer-oriented standards, organize around the eleven mission-based services, measure (quantitatively) the quality of services being delivered and develop a statistical

sampling plan. The organization is currently at the point of determining the mechanisms to define customer expectations for the eleven services. When completed, the quantitative results of the quality-assurance reviews will be included as performance measures.

Mission-Based Budgeting

To create a holistic management approach of complementary components, budgeting is a key consideration. Public organizations throughout the country have developed clever performance-measurement systems, quality systems, or budgeting systems. A belief underlying the approach in New York is that all of these components must be thought through in designing and developing a total system, though they do not need to be (and should not be) brought on line at the same time.

The premise that the budgeting system works from its ability to define what services the organization has to offer and how much of each service a dollar will buy. The control element holding the agency accountable then must be a results-oriented quality assurance review. For budgeting purposes, this review should be performed outside of the organization being evaluated.

Developing a service-based budget should also simplify the decisions as to what services to contract out, performed with state forces, or privatized. Using tasks as a service basis also lays the groundwork for activity-based costing for value comparisons necessary if service-provider decisions are to be based primarily on economic considerations.

BALANCING A FAMILY OF MEASURES: KEY RESULT AREAS

"No measure stands alone" is becoming a familiar phrase in the vocabulary of performance measurement. Management is no longer aimed solely at increased productivity or lower costs. High productivity or low cost at the expense of quality, customer satisfaction, innovation, learning, and continuous improvement can be damaging to an organization's market position in a world economy no longer defined by the industrial production of commodities.

The characteristics describing excellent service delivery and sound organizational health shape the categories of performance that require measurement. Efficiency and effectiveness are the simplest means of classifying measurements and are frequently heard in political rhetoric.

Searching for the categories to paint a comprehensive picture of the organization's performance has led to an approach discussed by Robert S. Kaplan and David P. Norton in a series of Harvard Business Review articles detailing what they term "The Balanced Scorecard."[6]

THE BALANCED SCORECARD AND KEY RESULT AREAS

The critical premise underlying the balanced scorecard is that organizational success is a consequence of manager attention being devoted to the entire family of factors that are critical for high-quality, profitable service delivery. The factors that must be both balanced and continuously improved upon are generally referred to as *Key Result Areas*. Though more than a dozen such areas have been identified, the balanced scorecard focuses on four that are critical for understanding and diagnosing the total organization. The four key areas consist of views of the organization from the following perspectives: 1) *financial, 2) internal business, 3) customer*, and *4) innovation & learning*.

The Financial Perspective asks "how do we look to shareholders?" In the public sector that translates to taxpayers and the control agencies. Frequently this is the only perspective anyone looks at, generally from a gross input standpoint, and rarely from a value creation or performance basis. In developing financial measures for the Transportation Maintenance Program, managers are asked to develop measures that they could use to find whether their part of the organization is making best possible use of fiscal resources entrusted to them in delivering services. At the operational level, these measures have focused on appropriate use of overtime and on controlling support costs.

The Internal Business Perspective asks "how must we excel?" From a maintenance operations perspective, this involves efficient use of labor, equipment, and materials; providing quality service results; minimizing rework; and rapid response. At the operational level, measures of labor efficiency have been developed and a quality-assurance system is under development. Though there is agreement that rework and response time are important also, meaningful and useful measures have thus far proven to be elusive.

The Customer Perspective asks "how do our customers see us?" What does the public think of services delivered by the Maintenance Program? Commonly there are two aspects to this question. The first is the priority of service *importance*- how do our priorities align with those of the traveling public? The second concerns organizational *performance* in delivering services, how

good a job do we do? One such survey was linked to individual counties as performance measures. The goal was to define this practice through a combination of winter and summer seasonal perception surveys.

The Innovation and Learning Perspective asks "can we continue to improve and create value?" This is the perspective that is generally the most difficult to define in the public sector due to the bureaucratic systems controlling most agencies. Bureaucracy operates on a basic principle that is at odds with *kaizen* (continuous improvement). An aim of bureaucratic systems is rocklike stability (rational division of work by function, authority and structure to persons who work in a controlled manner according to strict standards, rules and procedures)- hardly a system where innovation can flourish. Contrast this with the philosophy of total quality management advocated in Deming's fifth point for management: "improve constantly and forever every process for planning, production, and service," or his sixth point: "institute training on the job," or his eighth: "drive out fear," or his twelfth: "remove barriers that rob people of pride of workmanship . . . ," or his thirteenth: "institute a vigorous program of education and self-improvement for everyone."[7]

To highlight these values innovation and learning are included as the fourth area for performance measurement. At the operational level, innovation itself has been difficult to measure directly. To develop a bureaucratic paper trail effectively stifles (formal) innovation. Rather than attempts have begun to measure innovation directly, videotaping practices and creating teams of peers to review those practices and share ideas, and have been received enthusiastically. The underlying belief is that innovation is best encouraged through peer exchange and by creating an atmosphere of competition for improvement.

Measures for learning and employee perceptions of the performance of an array of management areas have been developed for the operational level. These examine training hours as a percentage of total time available. The second measure looks at how purposefully the organization is managed through a survey of employee's perceptions of six key management practices: performance expectations, effective authority, teamwork, performance evaluation, rewards and recognition, and responsibility for results. The survey is completed by the manager and those supervised by the manager to determine both the subordinates absolute level of the perception of performance, and the relative differences in perception between how the manager and the manager's direct reports. Surveys by level and location have provided interesting results indicating where communication breaks down, the differences in perception of how the manager's view themselves and how others perceive them, and the differences between problems created by the manager as opposed to those created by the bureaucracy.

BUSINESS CYCLES, TRENDS AND THE OREGON MATRIX

One of the first lessons learned in developing performance measures was that transportation maintenance in New York functions on two distinct business cycles - summer and winter. This became clear through the iterative process of developing measures. Measures of overtime, labor efficiency, quality, and customer satisfaction were difficult to set goals for because of the forces that drive the weather-dependent winter season, as opposed to the much more planable summer season. The principles in organizing a winter operation also are much different from summer, as is the task mix. By separating the two major business cycles, measures much more closely model the operating conditions facing managers. Consistency of data models also improves significantly. The next step was to format the measures, reflect the balance of the key result areas, and provide a foundation for continuous improvement.

The Oregon Objectives Matrix

A common complaint voiced by managers concerning measurement is that every organization's operating environment is unique, so that comparisons between counties or regions are not legitimate. One key principle that resulted is that a county résidency, or a region is not different from itself. A measurement system must provide a foundation for continuous improvement by measuring current against past performance for the individual organizational unit being measured. The format that allowed for this (as well as for balancing key result areas) is the Oregon Objectives Matrix.

This was conceived by James Riggs and Glenn Felix at Oregon State University in the 1980's [8], and was adopted by Oregon DOT as part of their ground-breaking performance measurement effort.[9] Each performance measure is identified at the top of the matrix, and level achieved for the measurement period is listed along the side as an index ranging from a low of -5 to the measure's goal level of +10, with zero being the historical average performance level for each individual measure. Each measure can then be weighted, the index level achieved can be multiplied by the weight, and the results can be summed to provide an overall performance index ranging from -500 to 1000. Figure 1 shows the application of the matrix and graphically displays the results for the first 16

WINTER PERFORMANCE MATRIX
Wyoming County
SFY: 1995 - 96 PAY PERIOD: 15 - 23

	Fiscal Performance			*Internal Process*		*Customer Satisfaction*	*Innovation/Growth*	
	Efficiency Measures				*Effectiveness Measures*			
Level of Performance	**PP 16-2 % Overtime Hours of Total Regular Hours**	**% Direct Overtime Hours of Total Overtime Hours**	**% Support Cost of Total Costs**	**Labor Efficiency**	**Quality Assurance Survey Result**	**Public Perception Survey Result**	**%Training Hrs of Total Hrs**	**Employee Survey Result**
Goal = 10	**5.00**	**100.00**	**20.00**	**150.00%**	**100**	**3.5**	**7.00**	**144**
9	5.85	98.31	22.38	142.86%	96	4.5	6.53	136
8	6.70	96.62	24.76	135.71%	91	5.5	6.06	129
7	7.55	94.93	27.14	128.57%	87	6.5	5.59	121
6	8.40	93.23	29.53	121.43%	83	7.5	5.12	113
5	9.25	91.54	31.91	114.29%	79	8.5	4.65	105
4	10.10	89.85	34.29	107.14%	74	9.5	4.18	98
Baseline = 3	**10.95**	**88.16**	**36.67**	**100.00%**	**70**	**10.5**	**3.71**	**90**
2	17.98	84.08		87.50%	60	12	2.86	75
1	25.00	80.00	35.00	75.00%	50	13.5	2.00	60
Score for Period	18.90%	93.30	30.03%	132.23%		7.6	0.9	82
Level Achieved	1	5	5	7		5	1	2
Weight	10.00%	10.00%	5.00%	20.00%	20.00%	15.00%	10.00%	10.00%
Total	0.1	0.5	0.25	1.4	0	0.75	0.1	0.2

Performance Index
3.3

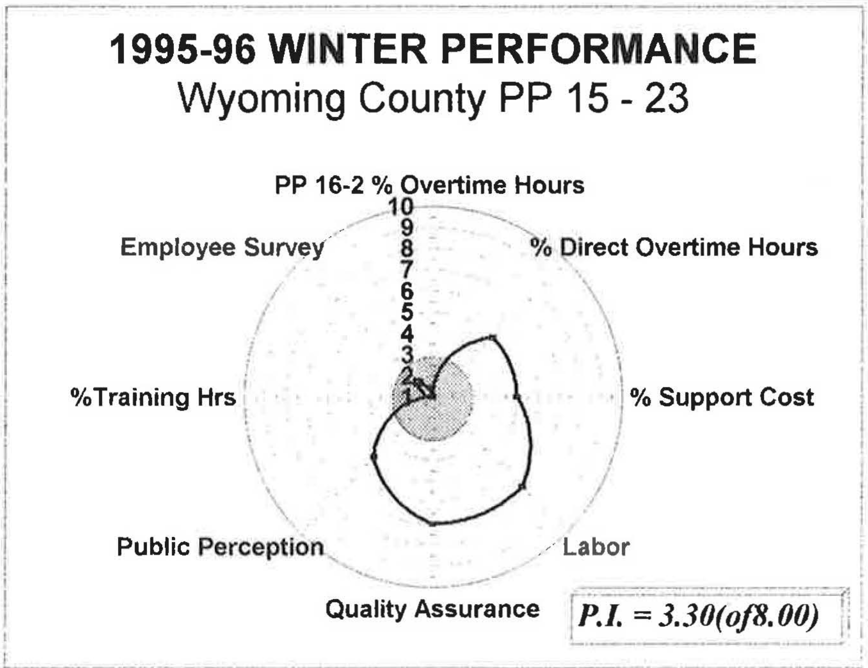

FIGURE 1 Application of the Oregon objectives matrix for a residency.

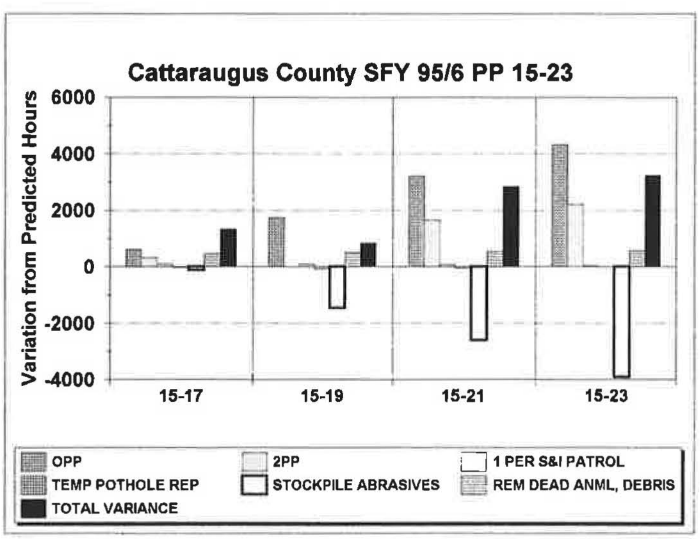

FIGURE 2 Trends in variation for key winter tasks.

weeks of the 1995-96 winter season for a county in western New York.

Trends

Information is useful only in a form that can create a contextual meaning. Snapshots of data are dangerous in the wrong hands, since there is no context to make them meaningful. Information from a single measurement cycle (one matrix) provides only a point on a piece of paper. What is important to look for are measurement trends, typically of at least three periods tending in specific direction (upward or downward). These could be trends in overall performance based on an overall performance index, or trends for individual measures. Figure 2 shows trends in year to date task variation for key winter activities as compared to what would be predicted if they worked each task at their own 3-year average productivity rate. Understanding the variations that occur in performance of the organization provides a key for managers using measurement as a diagnostic control mechanism.

VARIANCE, PARETO ANALYSIS, AND THE RELATIVITY OF MEASUREMENT

Consistency and accuracy are the two critical elements of a reliable database. While accuracy is very important for understanding such absolutes as volume or cost, consistency also is important from the standpoint of relative improvement. Getting everyone in an organization to measure an acre of mowing to the same area can be a difficult task; much can be gained by the organization measuring consistently, even if units being measured vary significantly. If one unit's actual measurement of an acre is consistently 20,000 square feet and another's is 40,000 square feet relative improvement or failure can be ascertained, even though accuracy of the total combined acreage is a meaningless number. To evaluate variation in performance trends, it is critical to maintain a consistent database, and accuracy is much less important. The implication for maintaining the integrity of a database is that task definitions, task scope, and units of measurement for individual tasks need to be fixed. Every change or refinement will undermine the integrity of a measure, until sufficient history and experience with the task is established to recreate a context.

Consistent measurement over time will allow for an understanding of the variance in performance of the area being modeled by the measure. This is the same principle found in measures of the stock market like the Standard and Poor's 500 Index. This concept in conjunction with Pareto analysis is particularly useful for measuring something like labor efficiency.

Creation of a graph to track trends in task variance begins with a Pareto analysis of the previous three years of labor hours. This involves creating a list of tasks by hours consumed from highest to lowest, and including only those that add up to 80% of the total hours for the three years. For counties involved in our pilot, this amounts to 14 to 20 tasks in the summer and fewer in the winter. This immediately reduces the roughly 100 "trivial many" tasks to the "vital few" involving less than 20 tasks. Tasks beyond those making the Pareto cut typically average less than 2% of total hours, so a focus on these would provide very little impact on aggregate labor efficiency. (The same analysis could be performed from a fiscal standpoint by substituting costs for hours to determine which tasks drive financial performance.)

For each task passing the Pareto cut, three-year average hours is divided by three-year average accomplishments to determine hours per accomplishment over the three-year period. Then current year-to-date accomplishments are multiplied by the three-year hours/accomplishment to predict the labor hours required if the task was performed at the same rate. Subtracting actual year-to-date hours from predicted hours then generates the *variance* from predicted hours. This is done for every Pareto task, variances summed to provide total variance. This is similar to profit or loss, except that the currency is hours. Total predicted hours divided by actual hours, expressed as a percentage, becomes the measure of labor efficiency.

Task variances graphed for each measurement period then demonstrate performance trends. Another useful feature of this graph is that hours gained or lost are directly related to the number of hours used, so that improvement efforts can be focused on activities being performed most often where productivity improvements will create the most hours for performing additional work.

This concept has been extended for use at the regional level to create a different context for trends in task variance. (In New York, eleven DOT regions are subdivided into county maintenance residencies.) A Pareto analysis is performed at the regional level from the aggregate data of all county residencies in a region and a regional three-year average rate of hours per accomplishment is established for those tasks. Then variance for each task passing the Pareto screen is calculated, based both on the region's hours per accomplishment and the individual residencies. The result demonstrates whether a residency is improving or failing,

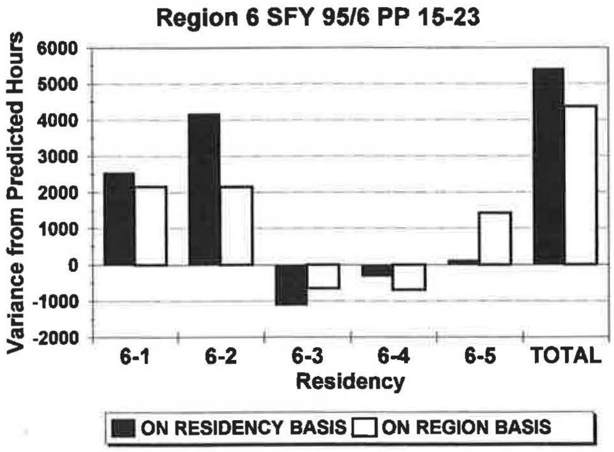

FIGURE 3 Total variation in task performance for residencies in the Hornell region for the 1995-96 winter season.

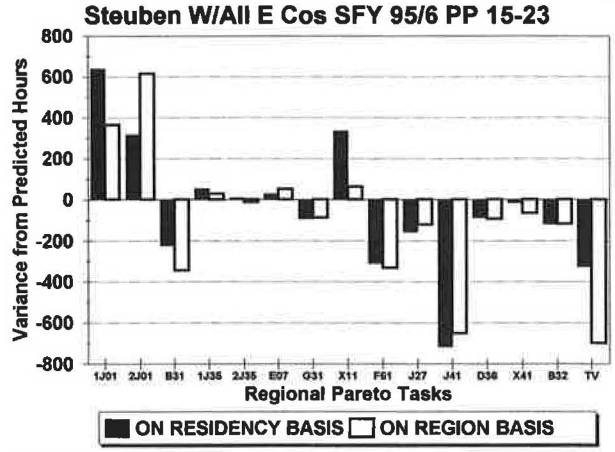

FIGURE 4 Winter task variance for a residency.

compared to their own past performance and against average performance within the region. For example, a residency's performance for a task could improve against its own past performance by a significant percentage, and still be significantly below average performance in that region. For the region as a whole to improve, low performers in key regional tasks must be evaluated to attempt to bring them up to the region's rate. Figure 3 demonstrates which residencies are improving or losing overall productivity compared to their own 3-year average rate (on residency basis), and compared to the average rate for the region (on region basis). An important assumption here is that the region is homogeneous.

To test this hypothesis, the coefficient of determination is calculated comparing a residency's performance to the region's. If the coefficient is close to 1.0 it can be assumed that in general the hypothesis is true. The same calculation can be performed for a residency, comparing its current performance to its three-year average to determine whether the data are behaving consistently. If not, the same variance chart can be used to address the data in detail by pointing out tasks that are highly variable. An analysis of the residencies in Figure 3 had coefficients greater than 0.90 when compared to the regional average showing that the residencies behave very much like the region as a whole with the exception of Schuyler County. Further analysis demonstrated that though productivity did not relate strongly to the region it did not relate strongly to its own history indicating inconsistent data collection, not necessarily indicating that conditions in that county being different from any other county. Figure 4 shows a residency that is under performing both in comparison to both their own historical performance and the region's. Their efficiency for the period at 97.43% compared to themselves and 94.47% compared to the region resulting in a loss of 325 hours on the residency basis and 698 hours on the region's. The tasks driving down overall performance are primarily tasks B31- Temporary Pothole Repair, F61- Maintain Guide Rail, and J41- Mechanical or Manual Clearing of Snow and Ice.

Upper and lower control limits are also set as part of the variance charts to inform managers which tasks are varying beyond the limits of normal error. For the residency in Figure 4 the tasks falling outside control limits are 1J01 and 2J02 - One and Two Person Plowing, and J41. Task X11 - Maintain Signs exceeds the upper control limit on a residency basis only.

At the statewide and regional levels similar analysis is performed, except that rather than use Pareto analysis to determine which tasks to focus on, tasks are separated into each of the eleven mission-based the individual services that are delivered statewide. The analysis at this level is cost-based rather than time-based. From this a theoretical figure can be calculated of dollars earned or lost due to variation in performance.

CONCLUSIONS AND LESSONS LEARNED

The most important lesson from trying to implement a performance-measurement system is that this process is not about measurement. The consequences of the measurement-development process are measures, but no real understanding of the mission of the organization, what services support that mission, and what roles people in the organization play in delivering service.

Without strong, knowledgeable and committed leadership, performance measurement cannot be successful. The organization must understand clearly what its strategic interests are, who its stakeholders and customers are, and service priorities and characteristics are essential in shaping services to the requirements of the organization's customers. This is a significant departure

from the traditional internally focused, and reactive organization.

Though the effort is difficult, and emotionally as well as intellectually challenging, it is worthwhile to take advantage of the opportunity for using performance measurement to bring meaning back to the term *public service,* and to simplify and clarify the organization's internal workings to make work purposeful, understandable, manageable and meaningful.

REFERENCES

1. Wipper, L., "Performance Measurement: Producing Results at the Oregon Department of Transportation", Transportation Research Board, Washington, D.C., 1993.

2. Cohen and Brand, *Total Quality Management in Government: A Practical Guide for the Real World*, Jossey-Bass Publishers, San Francisco, 1993.

3. Martin, R., "Texas Tomorrow: Strategic Planning and Performance Budgeting", Presentation to NYS-GFOA Conference, Albany, N.Y., 1994.

4. Hutchins, G., *ISO 9000: A Comprehensive Guide to Registration, Audit Guidelines and Successful Registration*, Oliver Wright Publications, Essex Junction, VT., 1993.

5. Kaplan and Norton, "The Balanced Scorecard -- Measures that Drive Performance", "Putting the Balanced Scorecard to Work", "Using the Balanced Scorecard as a Strategic Management System", Harvard Business Review, Boston, January -- February 1992, September -- October 1993, January -- February 1996.

6. Kaplan and Norton, *The Balanced Scorecard: Translating Strategy into Action*, Harvard Business School Press, Boston, 1996.

7. Deming, W., *Out of the Crisis*, Cambridge University Press, Cambridge, MA, 1986.

8. Felix, G., "Performance Measurement In Oregon State Government: Using The Productivity Matrix", Howard Publishing Company, Tualatin, OR, 1991.

9. Wipper, L., "Performance Measurement: Producing Results at the Oregon Department of Transportation", Transportation Research Board, Washington, D.C., 1993.

PERFORMANCE MEASURES IN THE PENNSYLVANIA DEPARTMENT OF TRANSPORTATION

Ronald D. Doemland and Richard Harris
Pennsylvania Department of Transportation

BACKGROUND OF PERFORMANCE MEASURES

In the early 1980's the Pennsylvania Department of Transportation (PennDOT) embraced the concept of Management by Objectives and developed a series of measures and management reports to track organizational performance. Three major reports were devised: 1) The Executive Summary (Blue Book) tracks approximately 300 measures and are reviewed monthly at the Secretary of Transportation's Executive Staff meeting; 2) The District Summary (Green Book) tracks highway design, construction and maintenance activities in each of the eleven engineering districts; 3) The County Summary (Red Book) tracks highway maintenance activities in each of the 67 counties located throughout the eleven districts.

About this same time we developed a system to measure county highway maintenance performance which we refer to as the "County Accreditation Review System (CARS)." This system consists of approximately 20 measurable activities performed in every county and they are weighted and scored on a five-point scale. The measures address personnel issues, equipment management, field operations and office operations. The results are published annually.

In the mid-eighties we successfully measured personal productivity in our maintenance garages and made several cosmetic and ergonomic changes which impacted on our garage efficiency. We attempted to measure overall productivity in our highway maintenance operations, but our reporting systems were designed to track inputs and inventory, rather than outcomes. To achieve the goals of the study would have required a major upgrading of our maintenance reporting systems.

DEVELOPMENT AND GROWTH OF PERFORMANCE MEASURES

In the late eighties PennDOT piloted a matrix measurement concept developed by the Oregon Productivity Center, the "Organizational Performance Index (OPI)." This tool provides the ability to track our performance regularly and determine if we are making improvement based upon some predetermined indicators. With our successful implementation of OPI we modified the concept in the early 1990's and applied it to measuring customer satisfaction. We now use the Customer Service Index (CSI) throughout the Department to measure our performance as determined by our customers.

CUSTOMER SERVICE INDEX

Why measure customer satisfaction?

- If you don't measure it, you can't improve it.
- It allows you to benchmark.
- It provides the opportunity to set goals and direction.
- It helps you justify your resources and your existence.
- Provides feedback to employees.

The Customer Service Index (CSI) is a tool for all PennDOT managers and employees at every level to monitor and evaluate customers' perceptions of their Service Delivery System. The Service Delivery System is defined as all the components, physical and procedural, that people have at their disposal to meet their customers' needs. An example of the relevance CSI would have to certain areas of PennDOT would be how our customers are affected by county maintenance activities (*maintenance, roadside rests, etc.*). Also internally, how well support Bureaus (*Fiscal, Personnel, Office Services, etc.*) provide services to each other and us.

CSI is based on a matrix - a diagram of rows and columns. The rows and columns represent measures that portray customers' perceptions. The measures are established in a combined effort of managers, employees, and customers. The computed index numbers are used to gauge the relative change in a quantity. The index is used to track trends and significant changes in needs and perceptions.

The CSI process is a 3 Stage process with 15 Steps.

Stage 1, Laying the groundwork	6 Steps
Stage 2, Building the matrix	6 Steps
Stage 3, Using the matrix	3 Steps

In Stage 1, the following steps are followed:

1. Create a Vision
2. Determine a Mission
3. Identify Goals and Objectives
4. Identify Customers
5. Identify Products and Services
6. Identify Moments of Truth

In Stage 2, the matrix is built by following the 6 steps listed below:

7. Identify preliminary measures
8. Clarify measures with customers
9. Assign weights to measures
10. Determine current performance through customer surveys
11. Establish long range goals for the measures
12. Complete the matrix

In stage 3, the last three steps are:

13. Determine periodic performance and post and share the matrix
14. Review results
15. Determine the need for and implement process improvement strategies to improve customer service

PennDOT piloted the CSI in twelve of its 67 County Maintenance Organizations in 1994. Surveys were sent to 400 random customers in each of the 12 counties (4800 total - 21.2% response rate). Those items which our customers felt are important were:

Highways and Bridges
- Good ride quality
- Good winter maintenance services
- Visible traffic line paint
- Easily understood signing

Work Zones
- Adequate warning signs
- Minimal delays
- Clearly identified travel lanes

Services
- Prompt service
- Knowledgeable staff
- Courteous service

The first statewide survey was distributed in September 1995 in all 67 counties. Again 400 random samples were distributed (26,800 total - 32% response rate). While results are county specific, statewide averages were: (on a scale of 1-5)

Highways and Bridges	
■ Ride Quality	
– Interstate	2.62
– Traffic Routes	2.62
– Secondary Routes	2.29
■ Snow and Ice Removal	2.92
■ Traffic Line Painting	2.95
■ Directional Highway Traffic Signs	3.14
Work Zones	
■ Warning Signs	3.59
■ Travel Lanes Clearly Identified	3.32
■ Delays	2.70
County Services	
■ Promptness	2.91
■ Courteous	3.33
■ Knowledgeable Staff	3.15

In summary, CSI

1. Measures customer satisfaction;
2. Provides opportunities for Improvement; and
3. Creates customer-driven organization.

FUTURE DIRECTION OF PERFORMANCE MEASURES IN PENNDOT

In 1995 the Department invited 50 partners from all modes of transportation to attend our Strategic Planning Conference and ensure that our goals were customer focused. Out of this conference came eight major goals. To monitor these goals a new report was constructed in 1996. We overhauled the executive report known as the Blue Book. It no longer tracks performance by the 300 measures, but tracks achievement of the eight goals of the Department. The measures are more outcome based and customer driven.

The County Accreditation Review System (CARS) is going to be redesigned based upon customer feedback. Customers have already stated that traffic lines are important to them. With the current CARS we would rate the county on the quality of their lines, not taking into account that there are many others who contribute to the success or failure of the county's traffic line program. The future CARS will use the OPI concept and will identify the critical measure for each organization involved in the traffic line program. It will become readily

apparent which entity is pulling the aggregate score down and the appropriate attention and resources can be so directed. This will cause the Department to look at line painting as a Department responsibility, and not just the county. Of course, traffic line paint is only one example.

The Department is going to attempt once more to measure garage maintenance productivity by use of a fleet maintenance consultant.

The Department is beginning a proof-of-concept pilot with Lehigh University's Iacocca Institute to implement the concept of "Agility and Virtual Organizations." This concept maintains that the Department would pursue virtual, i.e., temporary partnerships with whoever is required to meet the impending customer need. To do this will require us to become agile and to forge alliances quickly with minimal red tape. This concept, in its early planning stage, will lead to some measures we have yet to fathom.

ECONOMIC EVALUATION OF TRUCK COLLISION WARNING SYSTEMS

James York and T.H. Maze
Iowa State University Center for Transportation Research and Education

ABSTRACT

Collision warning devices are automatic systems to warn drivers when a potentially dangerous situation occurs, and thus allow the driver to take corrective actions. This paper addresses the potential economic value of warning truck drivers of dangerous maneuvers or danger due to failure to make a maneuver. The central issue addressed by the research is the value of warning the driver when he or she is making or about to make an unintentional lane change or roadway departure. Such unintentional lane changes are a symptom of drowsiness and inattentiveness. Also evaluated were the potential benefits of warning the driver in several other potentially dangerous situations.

The lack of exposure information in publicly available databases was one of the difficulties found in our attempts to analyze the per mile cost of accidents by maneuver. To accomplish this analysis, a database was created to support the estimation of accident cost by accident type using accident records over a three-year period from six truckload motor carriers. Together, the six motor carriers accounted for almost 350 million miles of truck travel during the three-year period with 264 accidents.

The analysis found that a collision warning system which alerted a driver to a potential accident due to an unintentional lane change or roadway departure only was not likely to be cost effective. However, a system which could warn of potentially hazardous situations when other maneuvers are being made (e.g., longitudinal warning in addition to warning during lateral maneuvers) could be very beneficial.

INTRODUCTION

Collision warning systems are a member of a family of systems categorized as Intelligent Transportation System (ITS) Collision Avoidance Systems (CAS). In general, CASs either passively or actively facilitate the avoidance of a collision. A collision warning system is a passive system which alerts the driver to take an action to avoid a collision, while an active system would intervene in the control of the vehicle to avoid a collision. Collision avoidance systems are categorized into five different types of systems.(1) They include:

- Longitudinal systems which look forward and/or rearward from the vehicle to maintain safe distances from other vehicle and objects.
- Lateral systems which look to the side of the vehicle to avoid accidents involving lane changes and roadway departures.
- Intersection systems which provide inputs from on-vehicle or infrastructure mounted devices to warning of a potential accident in and around an intersection.
- Vision enhancement systems which enhance the driver's ability to detect hazardous situations.
- Safety readiness systems which monitor the driver's and vehicle's safety worthiness.

Although technologies to support each of these types of systems are currently available, the introduction of the systems partially depends on the expected accident cost savings exceeding the cost of the device. This paper discusses research conducted to determine the potential cost savings attributable to a truck-mounted lateral warning system. The specific focus of the research is on systems which alerts the driver to an impending lane departure. In addition, data were collected which made it possible to infer the potential benefits of systems warning of collisions involving other maneuvers.

Unintentional lane departures are a result of inattentiveness or drowsiness, commonly caused by driver fatigue. Truck driver fatigue is estimated to be the contributing factor in 30 to 40 percent of all heavy truck accidents.(2) For example, a 1990 study of 182 fatal heavy truck accident found that 31 percent of those accidents were fatigue-related. In a 1994 National Highway Traffic Safety Administration (NHTSA) study it was estimated that driver inattentive, drowsy, or driver asleep cited as the major factor related to 31.5 percent of all fatal accidents involving combination-unit and single-unit trucks involved in single vehicle roadway departure accidents.(3) Clearly, accidents involving fatigue and unintentional lane changes or road departure are important and costly. The purpose of the research described here is to determine the potential value of being able to avoid such accidents.

ACCIDENT DATA

The objective of the research was to determine the cost associated with accidents involving specific vehicle maneuvers in advance of the accident (e.g., unintentional lane change or land departure, head-on, rear-end, turning, etc.). Depending on the maneuver prior to the accident, the researchers could interpret if a specific collision warning function would assist in avoiding the resulting accident.

There are publicly available accident databases but they generally do not provide adequate detail on the economic cost per accident and/or on exposure. For example, the Fatal Accident Report System (FARS) kept by the NHTSA contains information on fatal accidents for heavy trucks. It was deemed that the FARS and other publicly available sources of truck accident data do not offer the needed level of detail.

Because data with sufficient detail was not readily available, raw data were collected from trucking firms. Because truckload operations are more subject to long hours of operation over long distances (as opposed to less-than-truckload operations), the truckload segment of the truck industry was isolated as the subject population. Candidate Class I carriers (gross revenue greater than $10,000,000) in and around Iowa were selected randomly. Ultimately six carriers agreed to have their safety records summarized into an analysis database. The data collected for each carrier included accidents information and exposure data for a three-year period from July 1, 1991 to June 30, 1994. In total, the trucks in the six fleets traveled 345 million miles during the three-year period.

Data Elements Collected

In advance of determining which data elements to collect, a review was conducted of the literature to determine variables which are believed to have a significant impact on truck accident rates. Based on this review, a list of data elements related to the driver, the roadway (at the location of the accident), the vehicle, and the accident itself were identified. Data were only collected for preventable accidents. Accidents which were non-preventable were deemed accidents which were unavoidable and the driver would not be assisted by the presence of a collision-warning device.

Driver Data Elements

These elements identify relevant attributes of the driver at the time of the accident. The data elements collected include:

- The driver's age at the time of accident.
- The driver's experience as indicated by the number of years of professional driving experience.
- The driver's length of tenure with the motor carrier.
- Whether or not the driver had formal training.
- The driver's relative familiarity with roadway as indicated by distance from the motor carrier's base of operations. Distance was defined by less than 50 miles from the base of operations, more than 50 miles, and out-of-state.

Other desired data elements which are believed to be related to accident rates were not readily available, even from the motor carrier's records. This included information on the driver's hours of service at the time of the accident and the medical condition of the driver.

Roadway Data Elements

These data elements are related to the environmental conditions at the time of the accident and properties related to condition of the roadway. These elements included:

- The roadway type at the location of the accident categorized as urban or rural, the number of lanes (two or four lanes), and whether the facility was built to freeway standards.
- The weather condition and weather related pavement conditions at the time of the accident, including whether the pavements was dry, wet, or icy, whether it was sunny/clear or overcast, and the existence of precipitation (rain, snow, or sleet).
- The direction of travel when the accident occurred.

Vehicle Data Elements

These are data elements which deal with the characteristics of the truck and the load at the time of the accident. These elements include:

- The truck configuration at the time of the accident.
- Whether the truck was loaded at the time of the accident and the type of cargo.
- The trailer type (e.g., tanker, flatbed, dry van, etc.), the model of the trailer, and trailer length.

Accident Data Element

These are data elements which are specific to the accident. They identify the vehicle maneuver leading to the accident and severity of the ensuing accident. The data elements collected included:

- The time of day of the accident, the day of the week, and the time of the year.
- The vehicle maneuver immediately preceding the accident. The categories of maneuvers included:
  - Unintentional lane change;
  - Turn-right or turn-left at an intersection or driveway;
  - Swerving;
  - Longitudinal movement (for example, as a result of rear-ending a vehicle in front or as a result of broadsiding another vehicle in an intersection);
  - Slowing;
  - Passing; and
  - Intentional lane change.
- The type of impact with a fixed object or another vehicle. The impact maybe a sideswipe, rear-ended, broadside, etc.
- The direct cost associate with the accident. These data were tabulated from the motor carrier's records and insurance company records. The cost information collected included:
  - Costs to repair or replace the participant motor carrier's truck and/or trailer due to the accident;
  - Cost to repair or replace the other involved parties vehicle and/or property;
  - Cost of medical expenses for all injured parties;
  - Cost related to cargo loss or damage; and
  - Miscellaneous cost such as site cleanup, towing, vehicle downtime, and lost work or workers' compensation claims.

Data Collection

Between one to three days were spent at the site of each participating motor carrier. After interviewing key motor carrier staff members, data were collected at each of the six motor carrier's offices following five steps. The steps are:

- Review of the motor carrier's accident register. All six participating carriers keep records for accidents in their register, although they are legally only required to keep a register of accidents in which the damage sustained by any involved vehicles requires its removal from the accident scene, or injuries to involved parties requires medical attention away from the scene, or a death. From the register, accidents were identified, the date of the accident, and the driver involved in the accident.
- The individual accident files were reviewed for each accident identified in the first step. This included carrier copies of accident reports, transcripts taken from accident observers, and insurance reports.
- Examination of the driver qualifications files. The pertinent data related to the drivers involved in accidents were recorded.
- The carrier's equipment inventory list was reviewed to gain information related to tractor and trailer involved in the accident.
- The carrier's fuel and mileage reporting system was reviewed to determine miles traveled by the carrier's trucks during the three-year period.

Database Characteristics

The participant carriers operated 1,175 heavy trucks during the three-year period, in aggregate they traveled 344,825,531 miles, and were involved in 264 accidents. On average, each truck traveled 97,823 miles per year and their fleets incurred about 0.766 accidents per million-miles. This is far below the national overall average for truck accidents of 2.04 per million-miles.(3) However, in the case study database, non-preventable accidents were not included making it impossible to make comparisons to national averages. The total accident cost was $3,476,812, slightly more than one cent per mile.

Although all the carriers are truckload carriers located in and around Iowa, there is considerable variability in the data between carriers. The average mileage per truck per carrier varied from 83,403 to 124,419 per year. Accident rates varied from 0.08 per truck per carrier to 0.61 per truck per carrier over the three-year study period.

ACCIDENT COST PER MANEUVER PRIOR TO ACCIDENT

A tabulation of the accident cost categorized by the maneuver immediately prior to the accident is listed in Table I. Accidents involving longitudinal maneuvers were the most costly and accounted for more than half the costs of all accident types. Assuming a collision warning device would allow a driver to avoid all preventable accidents involving a longitudinal maneuver prior to the accident and an average distance traveled of 100,000 miles per year,

TABLE 1 ECONOMIC ANALYSIS OF ACCIDENT COSTS BY MANEUVER TYPE

Maneuver Type	Total Cost	Cost per Mile	% Total Costs
Straight	$1,979,298.38	$0.0057	56.93%
Unintentional Lane Change	$532,148.17	$0.0015	15.31%
Turn	$451,178.53	$0.0013	12.98%
Intentional Lane Change	$287,015.18	$0.0008	8.26%
Slowing	$120,801.23	$0.0004	3.47%
Passing	$43,164.15	$0.0001	1.24%
Stopped	$18,134.03	$0.0001	0.52%
Merge	$15,990.12	$0.0000	0.46%
Backing	$12,492.50	$0.0000	0.36%
Unattended Vehicle	$5,736.00	$0.0000	0.16%
Swerve	$5,395.79	$0.0000	0.16%
U turn	$2,962.00	$0.0000	0.09%
Straight/Backing	$2,496.00	$0.0000	0.07%
Total Accident Costs	**$3,476,812.08**	**$0.0101**	**100.00%**

the average cost savings of avoiding these accidents is $570 per year. Assuming the collision warning device has a three year life and an eight percent per year cost of capital, the device could be priced as high as $1,450 before the cost of the device exceeds the potential cost savings attributable to eliminating all longitudinal maneuver accidents. Admittedly, it is impossible to predict what proportion of these preventable accidents would actually be avoided through the use of a collision warning system without conducting a large scale field trial of the systems in actual use. It is clear, however, that the price of the system must be less than the expected cost of the accidents which could be potentially avoided. Therefore, $1,450 represents a per unit price ceiling for a longitudinal collision warning system.

Accidents involving unintentional lane changes only accounted for 15 percent of the total accident costs. Assume that a collision warning device would allow drivers to avoid all unintentional lane change accidents and based on the same criteria used to evaluate accidents involving longitudinal maneuvers, the price ceiling for the device is $380. Given the relatively low potential cost savings, it is unlikely a system which only provides collision warnings for unintentional lane changes or roadway departures would be cost effective. When trucking firm managers were interview and asked about the relative cost of warning systems to avoid unintentional lane change or lane departure accidents, some comment that they believed they would be better off investing in additional safety training for their drivers. On the other hand, if the system were able to warn of likely collisions under several maneuvers (longitudinal maneuvers, unintentional and intentional lane changes, and turning accidents) and allow the drive to avoid accidents involving these maneuvers, the expected savings over three year life is $2,400 and these savings are in the neighborhood of the cost of current onboard technology. If the collision warning system can conduct other onboard electronics functions (e.g., trip reporting, vehicle location, communications, etc.) then the bundled systems including collision-warning functions become highly cost effective.

CONCLUSIONS

The purpose of the research presented in this paper was to determine the potential cost savings attributable to being able to warn a driver of an impending situation involving a preventable accident. The specific issue being addressed is what are the potential benefits of being able to warn an inattentive or drowsy driver of an accident situation resulting from unintentional lane change or a roadway departure. Analysis of accident data collected from six truckload motor carriers covering 345 million miles during three years found that accident costs were slightly more than one cent per mile. Accidents involving an unintentional lane change or roadway departure accounted for only 15 percent of total preventable accident costs, while accidents involving longitudinal movement accounted for slightly more than half of all accident costs. Given the relative magnitude of unintentional lane change and roadway departure accident cost, a device to perform only this function would probably not be cost beneficial. However, an onboard collision warning system which could detect several potential accident situations and particularly those involving a longitudinal maneuver are likely to be beneficial. If these systems can be bundled with other onboard ITS functions, these systems are likely to very cost effective.

REFERENCES

1. Allen, R.W., "The Driver's Role in Collision Avoidance Systems," *Collision Avoidance Systems Issues an Opportunities Workshop Proceedings*, Sponsored by ITS America, March 1994.

2. Knipling, R.R., and J.Wang. "Crashes and Fatalities Related to Drive Fatigue," *Research Note/*, U.S. Department of Transportation, National Highway Traffic Safety Administration, 1994.

3. Wang, J., and R.R. Knipling, *Single-Vehicle Roadway Department Crashes: Problem Size Assessment and Statistical Description*, Report DOT-HS-808-113, National Highway Traffic Safety Administration, 1994.

APPLICATION OF NCHRP REPORT 350 TO TMA SYSTEMS

J.M. Essex
E.A.S.I., Chicago, Illinois

The purpose of this paper is to briefly examine the importance of National Cooperative Highway Research Program (NCHRP) Report 350 and its implementation schedule upon you in maintenance operations. NCHRP Report 350 was published in 1993 and establishes the latest testing standards for highway safety hardware, i.e., crash cushions, longitudinal barriers, end terminals and truck mounted attenuators (TMAs), etc. This document has been accepted by FHWA and they have published an implementation schedule which is currently in its transition stage and will be in full effect for all safety hardware in August 1998. However, many states are specifying the use of "350" hardware now and will beat the FHWA implementation mandate.

The NCHRP Report 350 document introduces the use of different test or service levels intended to match their performance levels to the various levels of highways, i.e., Interstate, primary, rural, construction zones, heavy industrial roads. Thus, NCHRP Report 350 provides the user with an opportunity to specify an economic level of hardware crashworthiness matching the service level of the roadway. It provides you, the user, a means to compare crashworthy performance between competing systems by testing to *same* standard conditions. A word of caution here is that these are lab *test conditions* and are not necessarily referenced or related to "real world" or actual situations found in the field. They are, in fact, worst case extreme conditions designed to test the extremes of the hardware.

The tests vehicles do, however, attempt to represent the extremes of the current vehicle fleet by testing with both the low center of gravity, light car (820C) to the higher (by 13") center of gravity sports utility, van and pick-ups (2000P).

Energy Absorption Systems has committed to have systems meeting these "350" standards in all crash management market segments by the 1998 date. This approximately five year program represents $6 to 8 million investment.

TMA, specifically, is a life-saving device to make the working environment for highway crews safer. NCHRP Report 350 has specific standard tests for the first time at both the 70-kph (approx. old 45-mph level) and the 100-kph (approx. 60-mph) speeds. The decision on which of TMA systems is right for your operation should be based on work zone conditions or site considerations. Conditions such as (1) anticipated traffic speeds through the work zone, (2) number of lanes, (3) length of time crew will be in the work zones, (4) number of lanes, (5) ability and time to deploy other traffic control measures, per the guidance of the Manual on Uniform Traffic Control Devices (MUTCD), etc.

The best document to provide guidance for the user on how and where to use TMAs can be found in a March 1990 University of Tennessee report on the subject. This document was referenced and reprinted several years ago by the AASHTO Highway Subcommittee on Maintenance.

In summary, the importance of a new crash testing document affords you, the users, a method to specify hardware which is crashworthy and economically feasible for your situation. I have given a brief overview of the latest in TMA systems which allows you to enhance safety in your work zones.

EMERGENCY WARNING LIGHT TECHNOLOGY

Robert Cameron
Whelen Engineering

I am sure that the first highway maintenance vehicle had no warning lights like we now know. Probably the earliest attempt at a warning system was to use the vehicles' own headlights and taillights during daytime operation. When the first true attempt at a dedicated warning light for highway maintenance vehicles was made is also a mystery to me. The need for warning lights probably followed on the heels of the example set by public safety agencies such as fire, ambulance and law enforcement. These agencies differ from road maintenance vehicles by the fact that public safety vehicles are generally traveling faster than prevailing traffic, while road maintenance vehicles are generally moving slower than traffic or are stationary. As the numbers of motor vehicles on the road increased, so did the probability of collisions with highway maintenance vehicles. We now have a need for emergency warning lights on road maintenance vehicles. These vehicles fill the full spectrum from small vehicles such as supervisor's cars and tractor style mowers to mammoth snowplow trucks and portable bridge inspection equipment. Each vehicle has a different method of operation and a different profile. What works well on one vehicle may prove to be inadequate on another vehicle.

The purpose of warning lights is multifold. First and foremost they are to warn the general motoring public that a highway maintenance vehicle is sharing the road with them. With enough warning time an operator can make the appropriate adjustments to his driving, like braking or changing lanes. Since the general motoring public is warned, this creates a safer work environment for the maintenance personnel. By the use of warning lights we have a win-win situation.

Warning lights also may define the size, shape and purpose of a vehicle. The best example of this is to activate the four way flashers on your own personal vehicle. The rear facing signal lights flash simultaneously and the front facing signal lights also flash simultaneously. This defines the width of the vehicle when viewed from either the front or rear. Most states require any vehicle on a limited access highway that travel below a minimum posted speed to use their four way flashers. This type of warning system is required by law on all passenger vehicles. Multiple emergency warning lights mounted at the extreme edges of the vehicle will be more effective at defining the width of the vehicle than a single warning light. Again, the four-way flasher example reinforces this fact.

The color of emergency warning lights can provide a message about the agency using the lights. In most states public safety agencies use red, blue and clear lights for their vehicles. At this time there is no uniform standard regarding emergency lights that is embraced by all states. Amber seems to be the accepted color for road maintenance vehicles in all states. There is a limited use of blue in addition to the amber in some states located in the snow belt. Minnesota Department of Transportation uses blue in addition to the amber year round, while Alaska Department of Transportation defines the seasonal use of blue auxiliary lights. Colorado Department of Transportation uses blue light in addition to amber only while involved in a snow clearing operation. In this example the general motoring public is warned that a snow clearing operation is in progress and that certain types of equipment may be in use such as snowplows, wing plows and sand spreaders or deicing equipment. There is a move to separate the emergency warning lights from other lights used to provide a message. The use of arrow boards and other smaller auxiliary directional devices is on the increase. With greater speed and traffic density it is imperative that the general motoring public be alerted at greater and greater distances and that a course of action be suggested. These direction indicating devices range from full size arrow boards measuring 1.22 meters (4 feet) x 2.44 meters (8 feet) to miniature moving light displays measuring 10.16 centimeters (4 inches) x 1.12 meters (44 inches). Multiple functions are standard features on these direction indicating products and usually include a left indicating display, a right indicating display, a split display moving from the center toward both ends, and a flash display used for auxiliary warning when providing a direction is not necessary. The light display may be switched on or off and the function changed from the driver's compartment while the vehicle is in motion. This is a great advantage over directional devices that must have the display changed by hand. Some of the direction arrow devices even have an LED display that emulates the operation of the lighted arrow display, giving the operator confirmation that the device is working and in the proper function. The newest innovation in this product line is

the ability to modify the pattern in which the lights are displayed. For instance in the full size arrow board displaying a left arrow function, the lights can sequence from right to left one at a time, two at a time, three at a time, build to a solid left arrow, or flash the entire arrow on at one time.

Each state controls the use of emergency warning lights by legislation. They specify which agencies must use warning lights of a particular configuration and color. They also regulate the private use of warning lights by contractors and volunteer emergency personnel. In many states, the use of warning lights on private vehicles is by permit only. This type of control maintains certain standards and prevents the widespread proliferation of all kinds of warning lights on all kinds of vehicles. The over use of warning lights would dilute the urgency and meaning of the signal.

Certainly the legislative control of warning lights is an acknowledgment of liabilities involved in the use of emergency response or highway maintenance vehicles. It is also an acknowledgment of their responsibility to establish and maintain minimum requirements that emergency warning lights must meet. States also legislate the manner in which other vehicles are required to respond to emergency warning signals. This may be as sublime as courteously granting the right of way to a volunteer fire person or as stringent as pulling over and stopping for a fire truck or ambulance. In this fashion liabilities are identified and responded to in a prescribed, predictable manner. When dealing with an increasingly diverse motoring public, this is probably the best we can hope for.

Technology changes with time. During my twenty three-year tenure with Whelen Engineering Company I have seen many advances in emergency warning light technology. Without advances in technology we would be driving on tube style tires and we would still have breaker point ignition systems. It is imperative that legislative agencies and user agencies keep up with advances in technology. Anyone involved with computers knows how quickly technology changes and what those changes cost. What is hard to measure is what not keeping up with technology costs, especially when safety is the yardstick.

In the emergency warning light industry, the Society of Automotive Engineers, Inc. (SAE) is the organization that I am most familiar with. They publish recommended practices, test procedures, requirements and guidelines for the design and manufacturing of all kinds of automotive products. They are strictly an advisory organization, not an enforcement agency. Their committees and subcommittees are made up of individuals representing companies involved in the manufacturing of the products they are writing requirements for. This provides an interesting paradox. For all practical purposes the members of the committee are business competitors. There is a vested interest in not sharing proprietary information, and there is also an undercurrent to keep the standards low enough for all members to be able to meet them without advancing the state of technology. Why would a member vote to raise standards if it meant they would have to spend time and money on new technology to meet a higher standard? This is what I call the lowest common denominator syndrome. The advance of technology should not be stifled because an individual or company is unwilling or unable to keep up with the pack. This attitude does not serve the common good.

Emergency warning lights fall under the same laws of physics that rule all light. That intensity is inversely proportional to the square of the viewing distance. This is not a linear function, it is a logarithmic function. For example, as the viewing distance doubles, the intensity is reduced to one quarter of the original intensity. There are a number of environmental conditions, over which we have no control, that affect intensity such as snow, fog, rain, dust and smoke. These conditions can greatly reduce the distance that an emergency warning light is perceived.

When reviewing manufacturers printed literature it is important that the units of light measure are consistent. SAE uses candela-seconds as a standard unit of measure for all warning lights. Often times manufacturers will use candlepower, beam candlepower, joules, visible effective candlepower, peak candlepower, watts and watt-seconds as advertised units of measure. They are not all the same. Watts and joules are measures of power. Candlepower measures all light from ultraviolet to infrared. The light we are interested is the light we can see. This is the only light we can visually perceive as a warning signal. To convert visible effective candlepower to peak candlepower, multiply by 1,350. In this fashion a rather mundane number is magically converted to a much more impressive number with lots of zeros. This is good for the manufacturer advertising their product, and looks good on paper to the buyer. After all wouldn't you rather buy an emergency warning light with 2,000,000-peak candlepower instead of one with 1,500 visible effective candlepower? This is a good example of buyer beware.

The color of the dome or lens covering the light source also will have the effect of reducing light intensity. Lens thickness and color density are variables that affect attenuation. Thicker lenses and concentrated color density have a greater filtering capacity than thin lenses or weak color density. Placing a clear lens over the light source may reduce the intensity by 10%. Amber and blue lenses attenuate light intensity by approximately 30% while a red lens will reduce light output by up to 80%. It seems to be a paradox that the agencies with the greatest

need for long-range warning are using lights with the worst color for light output.

At this time, the color of the warning light is the only way of communicating with the motoring public. Different agencies are assigned certain colors they may use. There are prescribed procedures that must be followed when encountering a vehicle displaying emergency warning lights. What are most important is that the signal is powerful enough to be seen at a distance that will allow reaction time, and that the signal be accurate, so that the response is immediate and appropriate.

Our human nature causes us to respond to anything out of the ordinary, a new smell, a strange sound, or a bright flash of light. Motoring conditions can vary from the serene environment of a quiet country lane to the busy hustle of an urban superhighway exchange. We are used to hearing the noise of traffic as well as headlights, daytime running lights, taillights, signal lights and brake lights. The device that we use to produce the warning signal must stand out from background of visual distractions. The warning signal must be visually apparent and command attention. It must be bright enough to overcome bright sunlight during daytime conditions and yet not be blinding during nighttime operation. By the same token it must be powerful enough to penetrate adverse climatic conditions such as snow, fog, dust and smoke. Here lies the paradox. How bright is bright enough and how bright is too bright? SAE has published test requirements that warning lights must meet to be approved. There is a minimum light requirement that must be met, but the upper limit is not defined. Is it not interesting that our government has set stringent fuel economy goals for the future but they do not address raising the minimum warning light standards?

There are a number of devices that qualify as emergency warning lights, each with its own unique characteristics and flaws. SAE has separated warning lights into several categories.

360 Degree Warning Devices project light in a 360-degree horizontal plane. It will produce a regularly repeating pattern of flashes to a stationary observer. This flash pattern can be accomplished by several methods. The simplest method is to interrupt the power to the light source. SAE considers this type of device a Flashing Signal Device. An electronic or relay circuit similar to a turn signal flasher regulated the flash rate and on time. The benefits of this type of device are its relative simplicity and no moving parts. The down side of the Flashing Signal Device is that the light output is directly related to the power of the light source. This means if you want a more powerful beacon, you need a more powerful light source. A higher wattage bulb requires more energy to operate it. This type of device also suffers from the lag time that it takes the bulb filament to turn on and reach full intensity. For example consider a beacon flashing 60 times per minute and having a 50% duty cycle, that is each flash is equal to the dark time between flashes. The bulb filament must turn on, reach full intensity, turn off and extinguish in one half second. The flashing duty cycle is hard on the bulb filament, the result being relatively short bulb life. Generally speaking, there are relatively few Flashing Signal Devices in mainstream use.

The second sub category of 360 Degree Warning Device is the Rotating Signal Device. This device produces a moving beam or beams of light by rotating either the light source or sources around a fixed axis, or by rotating one or more reflectors, lenses or mirrors around a fixed light source. This style of light has many advantages over the Flashing Signal Device. The light source or sources are steady burn, thus giving a constant full intensity output. Lamp life is greatly increased over the flashing style of beacon. Through the use of mirrors, reflectors or lenses the light source is concentrated into a beam of definite arc width, rather than a 360-degree dispersion. This increases the intensity without having to increase the power of the light source. The drawback to this type of warning device is that it requires a motor to create the motion. Motors are subject to mechanical wear, and often perform poorly in cold weather conditions. When the light sources are rotated, such as on the familiar two-sealed beam rotating beacons, brush contacts are required to operate the light sources. Both the motor and the brushes can contribute to radio frequency interference (RFI). This interference generally gets worse with the aging and wear of the Rotating Signal Device. Beacons that use a fixed light source and rotate either reflectors or lenses suffer from inconsistent intensity and light distribution patterns. This is caused by the constantly changing relationship between the lamp filament and the focal point of the lens or reflector. One unique property of the rotating signal device is to project multiple colors by using colored light sources or lenses. When viewed from a fixed location, a regularly repeating pattern would be witnessed. This is most often seen on ambulances and fire equipment using red and white lights in repeating patterns. In spite of the many drawbacks to this design of warning device, it is well established in the marketplace and is produced by many manufacturers.

Another type of Emergency Warning Light is the Oscillating Signal Device. In this instance one or more beams of light are caused to turn back and forth through a fixed arc. The sum total of all arcs must add up to at least 360 degrees. Colored light sources or lenses could be used to project different colors in each arc, similar to the rotating signal device mentioned above. Depending on the

number of beams present, the arc width and the angular sweep, the stationary viewer may witness one color or a multiple colored pattern. Once again this is a mechanical assembly like the above Rotating Signal Device and will suffer all the same drawbacks of motors, connecting links, and brush contacts. This type of device, though never really popular, has for all practical purposes vanished from general use. It has been supplanted by the less complicated and more cost efficient Rotating Signal Device. The back and forth sweeping motion is certainly notable with this type of device and unique to its design, but there is no specific requirement that calls for the exclusive use of this device over any other approved warning device.

SAE recognizes flash rates from 1 Hz (60 flashes per minute) to 4 Hz (240 flashes per minute) in their document J 845. The main concern, however, is not flashrate, but effective intensity. The effective intensity is effected by three factors: flashrate, beam width, and the intensity of the light source. Let us examine each factor separately. If the other two factors remain constant and the flashrate is increased, then the effective intensity will be reduced. Conversely, if the flashrate is slowed down, then effective intensity will be increased. This argument can be taken to an illogical end, because as the flashrate becomes slower and slower, then the signal becomes more and more like a steady burning light. If beam width becomes the variable, then increasing the beam width will increase the apparent on time of the light, while decreasing the beam width will decrease the on time. Obviously increasing the intensity of the light source will increase the intensity of the beam and the generated signal. This is the more horsepower route most often taken. It is the easiest and most cost-effective way to get more light output in this type of design. With a higher wattage light source comes greater heat and more power consumption.

Designers have been experimenting with both the Rotating Signal Device and the Oscillating Signal Device since their inception with the intent of improving the warning signal produced. The laws of physics are always working against maximum efficiency in this type of device because energy is shared between the motor and the light source. Light sources have steadily improved from the incandescent filament bulb to the newer halogen cycle lamps, giving a brighter more truly white light with less heat output. The optics of lenses and reflectors can be modified to alter the beam width, or to produce rapid multiple flashes. The latest development in motor technology is the stepper motor. This motor can be addressed to either rotate through a complete circle, or to oscillate through a designated arc. To sum up mechanical warning lights, we are on a plateau and have been for some time. The marketplace is waiting for a technological breakthrough in this type of warning device.

The other major category of Emergency Warning Light is the Gaseous Discharge Warning Lamp, more commonly known as the Strobe. This type of device uses an electronic circuit to convert the direct current energy from the vehicle's electrical system, typically 12 volts DC, to a high voltage level generally between 400 and 600 volts. This high voltage energy is stored in one or more capacitors. A timing circuit triggers the release of this energy to be discharged into a lamp filled with Xenon gas. The strobe concept is parallel in principle to vehicular electronic ignition except that the strobe tube is substituted for the spark plug. Gaseous Discharge Warning Lamps range from low 2 watt output units generally used on fork lift equipment used indoors to 180 watt output units operating multiple strobe tubs, commonly used on ambulances and fire apparatus.

Credit for the invention of the Xenon strobe, in 1932, goes to Dr. Harold Edgerton. Strobes came to the vehicular warning light market in a round about way. They were commonly used in the photographic field, where they were triggered on demand. With the advent of an electronic circuit that allowed a regularly occurring flash rate, the Gaseous Discharge Warning Lamp was born. First used as a warning light on aircraft in the early 1960's, the strobe didn't appear in the vehicular marketplace until 1968. Strobe technology has made steady progress throughout the intervening years.

The first strobes were single flash devices. A single, short duration, high intensity flash was produced followed be a relatively long dark period, at the rate of 1 Hz. Being new, strobe-warning lights caused quite a stir when they were first used on the roadways. The motoring public was used to a less intense, longer duration flash. They claimed that this type of flash was irritating, disorienting and dangerous, especially at night. There was great controversy over the use of strobe warning devices during the late 1960's through the 1970's. Many manufacturers not involved in strobe technology engaged in smear campaigns to discredit strobes, claiming eye damage, brain wave interruption and the cause of epilepsy and sterility. This was an earlier example of the negative advertising style we are all so familiar with now. If those manufacturers spent as much time and money on research and development as they did on negative advertising then they too would be in the forefront of strobe technology. In retrospect, there were also enough independent studies to refute any negative claims about strobes. As a postscript to the above, most of the companies involved in the earlier smear campaigns are now selling strobe products.

The claim about strobes being irritating and disorienting at night was not without a basis in fact. During nighttime driving the eye is relatively dilated. A

high intensity short duration flash happens so fast that it doesn't let the eye react by constricting during the flash sequence. Therefore the eye continues to receive high intensity flashes into a dilated pupil. Being used on emergency response vehicles traveling at elevated speeds at night caused poor tracking of the emergency vehicle. Under these conditions the emergency vehicle could appear to move well over 100 feet in the dark period between flashes. A 360-degree rotating or oscillating device always seems to give off a witness level of light between flashes thus allowing better tracking at night. Adding a low candlepower incandescent glow light to the strobe device was tried to improve nighttime tracking. This was a temporary solution. It did improve nighttime tracking but now there is a secondary device requiring electrical power.

One of the principle advantages of the Gaseous Discharge Warning Lamp is its great efficiency of turning electrical power to light. There is only the primary electronic system which converts the vehicle's electrical energy to the high voltage energy used to fire the xenon strobe tube. There is no secondary system such as in the mechanical rotating and oscillating 360-Degree Warning Devices. Being fully electronic, there are no moving parts which are affected by vibration, wear and temperature extremes. Radio Frequency Interference (RFI) can be minimized with a good design and should not change with the aging of the strobe light. Mechanical designs suffer from increasing radio frequency interference with the aging and wear of the device. Motors and brush contacts wear and build up carbon on the contacts, creating arcing and high resistance contacts. This gets to be a run away situation that will eventually lead to the failure of the mechanical device.

Comparing a mechanical 360-Degree Warning Device to a Gaseous Discharge Warning Lamp of equal intensity will demonstrate that the strobe device consumes less than half the current than the mechanical device. This becomes significant when operating other emergency warning equipment such as high power two-way radios, sirens, medical support equipment, and spotlights. This kind of equipment when operated individually or in combination can overload the capacity of the vehicle's electrical system. This can lead to discharged batteries or, over a longer period of time, early failure of electrical components such as alternators, voltage regulators and batteries. Even though the alternator is rated at 80 or 100 amps, that is at operating speed. At idle these alternators may only produce 40 amps. This output is easily overcome with moderate electrical equipment use. A Federal regulation for ambulances, KKK1822C, addresses the current consumption issue and allows only 35 amps for the entire emergency lighting system. Some large fire apparatus manufacturers have gone to an automatic electrical load management system, whereby the electrical cannot be overloaded. As you can see from these examples the Gaseous Discharge Warning Lamp certainly helps the current consumption cause.

The first double flash strobe device was pioneered in 1974. This device produced two strobes flashed in rapid sequence followed by a relatively longer dark period. The first primary flash was the more intense of the two. The smaller secondary flash functioned as a fill-in flash, tricking the viewer's eye into seeing a longer duration flash. This double flash sequence produced a flash that approximated the familiar two-sealed beam 360-Degree Rotating Signal Device. Improvements in electronic components allowed this breakthrough without a corresponding increase in current consumption. This addressed the complaint that strobes were too irritating and disorienting. As Gaseous Discharge Warning Devices gained mainstream acceptance, many large agencies began using strobes in their fleets. Strobes became the warning system of choice and many specifications were written around this type of light to the exclusion of other types of warning devices.

A low power circuit was developed in 1978. This addressed the complaint that strobes were too bright for nighttime use. This circuit, activated by the operator or through the use of a photocell, reduced light output by up to 85%. One must understand that when the strobes are operating in the low power condition, they do not meet the light output required for a SAE class 1 approval. The low power feature should only be used when the vehicle is stationary. The use of strobes in the low power mode while in motion is not advised and could put the agency in jeopardy of litigation if they are involved in any kind of accident. Imagine the scene of a major nighttime multiple motor vehicle accident. Police cars everywhere, tow trucks, fire apparatus and ambulances all with their warning lights operating. There also will probably be people working around the accident scene treating the injured, moving wrecked vehicles and others directing traffic. We have all passed this type of scene at some time. Chaos abounds. With all the bright flashing lights you may have difficulty concentrating or seeing people directing traffic. Now the lights, whose purpose is to warn, now become a liability to the safe execution of an accident scene. This is where Gaseous Discharge Warning Devices operating in low power becomes an asset. I, personally, am opposed to the use of an automatic photocell circuit for the activation of the low power mode. First of all the strobe will not meet output levels for a certified Emergency Warning Light. For instance a snow plow truck whose hours of operation extend beyond the daylight hours and into twilight or nighttime. The photocell circuit would react to the reduced ambient light

available and at sometime shift the strobe warning system into low power mode. The vehicle operator may not be aware that this has taken place, and the vehicle is technically operating in an illegal condition. The second objection I have against photocell control is that the device is dumb. It is not able to ascertain what caused the reduced ambient light condition. It may have been caused by heavy fog, snow, smoke, or contamination built up on the photocell device itself. The use of a strobe in the low power-operating mode under these conditions is not only illegal, but potentially deadly. The control of the Emergency Warning Light System is better off left to the control of the vehicle operator. After all, the automatic high beam/low beam option on some luxury cars in the 1970's never became a mainstream product.

By the late 1980s and the early 1990s there were many manufacturers of strobe devices, ranging from low yield inexpensive devices for use by a stranded motorist to the high output professional devices for use by emergency agencies. The focus of research and development was to develop something that would make your device stand out from the crowd. Unique flash patterns with three, four, or five quick flashes per burst were tried by many manufacturers as well as constant high speed single flash sequences. All met with a certain measure of success. CometFlash7 was introduced with a four flash per burst flash pattern. This pattern is an expansion of the double flash concept whereby the first primary flash is significantly brighter than the three follow up secondary flashes. This flash pattern gives a 60% effective on-time. The benefits of this are better tracking at speed and better color saturation especially red.

The latest craze in Gaseous Discharge Warning Lamp technology is the ability to produce a multiple of flash patterns rather than only one pattern, be it single, double, or multiple. Microprocessor technology allows the operator to select the flash pattern by a switch control or the strobe device itself has a preprogrammed automatic sequence of flash patterns that repeat on a regular basis. At first examination this may seem like a cute gimmick, but it does have a very important application. Earlier we discussed that we react to changes from the ordinary. We are all familiar with warning lights and sirens, and in areas of high traffic concentrations they are the norm rather than the exception. They become ordinary and fail to capture the attention of the motoring public. Emergency vehicle operators have had to resort to switching their lights and sirens manually from one operating mode to another. Trying to pilot an emergency vehicle through traffic with one hand while operating the lights and siren with the other hand can be disastrous. Some of the latest generation of warning lights and sirens can be connected to the vehicle's steering wheel horn button. The entire warning system, both lights and siren, can be turned on, shifted from one operating mode to another, put into a secondary stand-by mode, or turned off by commands from the horn button. The vehicle operator never has to take his hands off the steering wheel or his eyes off the road. The ease of operation is simplified, and the risk of responding at speed is reduced.

One of the things we have gotten used to in our own personal vehicles is confirmation lights or gauges that indicate whether or not the equipment we have turned on is in actually working, or working properly. Over the years there were warning buzzers for door ajar, headlights left on, high beam indicators, low oil pressure, etc. Several years ago this concern was addressed with the introduction of diagnostic strobe equipment. Rather than relying on a lighted toggle switch or a pilot light which merely indicates that there is power to the switch, there is now strobe equipment that will give real time feed back from the Xenon strobe tube itself. A small LED panel in the operator's compartment gives a lighted LED for a strobe light turned on in the high power mode. If that strobe light is switched into the low power mode, the LED blinks once every four seconds. This keeps the operator informed that the strobe is operating in low power mode. If the Xenon strobe tube should fail to flash for any reason whatsoever, for instance a cracked lamp, a damaged cable, or if it merely becomes unplugged, the LED panel will blink once per second indicating a waning light not working. Knowing the condition of your warning system allows the operator to make an informed decision on how to respond to an emergency scene. In snow plowing operations that may last many hours, a warning light can fail at any time. It is especially important to know if your warning system is working properly and is visible to the motoring public. Taking this concept further is a warning system directed chiefly toward the law enforcement market. This system is fully diagnostic in real time as well as having a quick check feature. With the push of one button all warning lights, all accessory lights, and the siren are tested. Once again, any fault in the system is indicated on a control panel by a blinking LED. There is no need to operate each circuit separately and visually verify proper operation. The siren is tested at a frequency in the inaudible range, so it will not become a nuisance. Testing the warning system before each shift is a good idea and is part of the standard operating procedure, it often gets overlooked especially when it is raining or snowing outside. Without real time verification of the status of the warning system, the operator may be under the false impression that he is responding with all lights and siren working. This assumption can be dangerous.

This sums up where we began and where we are today. Where do we go from here? Certainly

improvements in electronic components will increase the efficiency of all warning lights whether fully electronic or electronically controlled mechanical devices. New light sources that produce more light output per watt of input. Right now there are several manufacturers involved in developing warning devices using high intensity discharge (HID) lamps. This light source has been used for years in the medical field. It produces five times the light output at half the current consumption of a halogen lamp. It will last roughly five times as long as that same halogen bulb. The disadvantage to HID is the cost and the fact that it needs an electronic support package to operate it. This again adds cost to the product. At this time it is used only in mechanical devices. As fiber optic technology advances, there may be a special place, or niche market in the warning light field for it. Self-diagnostic and verification features may filter down into lower cost devices.

One of the obstacles to progress in the warning product industry is allowing the minimum requirements to remain the same from year to year. There is little real incentive for manufacturers to spend money on research and development of new technologies when the products designed in the 1970s will meet minimum requirements. Most agencies will buy the least expensive product that fulfills the requirement they are obligated to meet. Our society has reaped the benefits from increasingly stringent standards. Pollution laws have become stricter, Cooperate Average Fuel Economy has been increased, building codes have been tightened up, motor vehicle crash standards have been reviewed and made safer, and the list goes on. Certification agencies should stay abreast of new technology and embrace improvements in warning devices. Specification writing agencies should look to the best warning system, rather than the cheapest light. Old technology should be left behind. Let us not lose focus on our goal, making our roadways safer.

FORWARD-LIGHTING CONFIGURATIONS FOR SNOWPLOWS

Peter Bajorski, Suman Dhar and Deniz Sandhu
New York State Department of Transportation

ABSTRACT

Snow and ice control is a critical maintenance operation for New York State—for each storm up to 68,500 lane-kms (42,500 lane-miles) of highway must be cleared. Visibility during plowing operations is often poor and further diminished by backscatter glare from the snowplow's own headlights as well as glare from lights of oncoming traffic. This paper summarizes results of a pilot study to identify forward (front-end) lighting configurations that might improve visibility for plow operations. During the 1993-94 winter, eight lighting configurations were tested; two of which were identified as potential improvements over the existing pattern. Simple procedures and forms were developed for collection of reliable data. Methodological issues in performing such experiments are discussed. Statistical methodology is presented, suitable for comparison of lighting configurations, but also applicable in other, broader contexts where a number of items are compared by several evaluators.

The full paper is presented in *Transportation Research Record 1533*, Transportation Research Board, Washington, D.C., 1996.

BRIDGE INSPECTION AND THE EQUIPMENT IT DEMANDS

Milton J. Luttrell, III
Aspen Aerials, Inc.

BRIDGE INSPECTION

During the bridge construction boom of the 1950's and early 1960's not much emphasis was placed on inspection and maintenance of bridges. The greatest number of bridges were built in the 1960's. This coincides with construction of the Interstate system. The increase in public and commercial traffic and the aging process means more bridge maintenance and rehabilitation work in the coming years. This also means that the structures will require close monitoring and in some cases the frequency of the safety inspections will need to be increased.

In December of 1967 the Silver Bridge, spanning over 2000 feet at Point Pleasant, West Virginia, suddenly collapsed into the Ohio River killing 46 people. The tragic collapse aroused national interest in the inspection and maintenance of bridges. Congress added to the Federal Aid Highway Act of 1968 a section which required the Secretary of Transportation to establish a national bridge inspection standard. The act also required the Secretary to develop a program to train bridge inspectors.

NATIONAL BRIDGE INSPECTION PROGRAM IMPLEMENTATION

During the 1970's many steps were taken to ensure proper inspection and maintenance of in-service bridges. The National Bridge Inspection Standards (NBIS) were created in 1971. These standards established national policy regarding the application of the standards, inspection procedures, frequency of inspections, qualifications of personnel, inspection reports, and inventory.

To implement the policies three manuals were developed: Federal Highway Administration's (FHWA's) Bridge Inspector's Training Manual / 70 (Manual 70), The American Association of State Highway Officials (AASHO) Manual for Maintenance inspection of Bridges, 1970, and the FHWA's Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges (the Coding Guide). These manuals were important to the early success of NBIS.

The Surface Transportation Assistance Act of 1978 established Federal funds for bridge replacement and required all public bridges over 20 feet in length to be inspected and inventoried in accordance with NBIS by December 31, 1980. In the 1980's more structural failures occurred which created a need for three new supplements to the Bridge Inspector's Training Manual / 70 (Manual 70): Culvert Inspection, July 1986, Inspection of Fracture Critical Bridges, September 1986, and Scour at Bridges Technical Advisory, September 1988. In 1991 the Federal Highway Administration published the Bridge Inspector's Training Manual / 90 (Manual 90). This manual replaced the Bridge Inspector's Training Manual / 70 (Manual 70).

INSPECTION PERSONNEL QUALIFICATIONS

The *Inspection Manager* is the person in charge of the organizational unit that has been delegated the responsibilities for bridge inspection, reporting, and inventory. This individual shall possess the following minimum qualifications: 1) be a registered professional engineer; or 2) be qualified for registration as a professional engineer under the laws of the State; or 3) have a minimum of 10 years experience in bridge inspection assignments in a responsible capacity and completed a comprehensive training course based on the Bridge Inspector's Training Manual, which has been developed by a joint Federal State task force.

The *Inspection Team Leader* is an individual in charge of a bridge inspection team. This person shall possess the following minimum qualifications: 1) have the qualifications specified as the person in charge of an organizational unit that has been delegated the responsibilities for bridge inspection, reporting, and inventory; or 2) have a minimum of 5 years experience in bridge inspection assignments in a responsible capacity and completed a comprehensive training course based on the Bridge Inspector's Training Manual, which has been developed by a joint Federal State task force; or 3) current certification as a Level III or IV Bridge Safety Inspector under the National Society of Professional Engineer's program for National Certification in Engineering Technologies (NICET).

AN INTERNATIONAL PERSPECTIVE

Other countries have experienced structural problems with their bridges. For example a major bridge collapse in South Korea aroused national interest in their bridge inspection and maintenance program. The South Korean

government is now developing a national bridge inspection program. South Korea is taking delivery of five Under Bridge Inspection Units as part of their commitment to a bridge inspection program. Austria, Russia and Vietnam also are reviewing their bridge inspection programs and are interested in purchasing Under Bridge Inspection Units.

BRIDGE TYPES

Through the years many different types of bridge designs have been developed and the need for many different types of equipment to access the structural components of a bridge has become necessary. The size and shape of the bridge will dictate the procedure used for inspection. A combination of primary structural components may be used in the construction of the bridge, thus requiring several inspection techniques for the same bridge. The bridge designs in existence today include: prestressed concrete multi-beam, girder floorbeam, slab span, concrete tee beam, adjacent box beam, steel box girder, reinforced concrete frame, deck truss, through truss, deck arch, through arch, suspension, cable-stayed, bascule, steel culvert, and concrete box culvert.

HANDS-ON INSPECTION

The concept of hands-on inspection has developed, as inspectors have realized that a thorough inspection of a bridge requires getting close enough to the bridge member or component so that it can be touched with the hands. During a hands-on inspection the inspector is more likely to see small structural deficiencies which require minor maintenance. If minor structural deficiencies are undetected they could become major repairs, or worse a failure of a major structural component. The owner of the bridge will be in a better position based on accurate inspection reports to schedule maintenance and repair of the bridges maintained in their bridge inventory.

INSPECTION ACCESS EQUIPMENT AND VEHICLES

By design different types of bridges require different inspection access equipment. For example, a one span prestress concrete multi-beam bridge with a horizontal span of 30 feet over a two lane gravel road with a vertical height of 16 feet, would probably require a ladder for the inspection of the structure. However, a bridge like the New River Gouge Bridge, near Beckley West Virginia, would require the use of sophisticated equipment such as an Under Bridge Inspection Unit (Inspection Access Vehicle) to perform a comprehensive inspection. Listed below are the types of equipment available.

Access Equipment

- *Ladders* can be used to inspect the underside of the bridge and the substructure units when height and access under the bridge is not a problem. Ladder usage should only include portions of the bridge that can be reached comfortably without excessive leaning.
- *Rigging* is sometimes used to access areas not reachable by ladders. Rigging is used in operations when the inspector will be at a location for a relatively long period of time. It is used more often for maintenance due to the fact that maintenance use often requires more time to complete a task.
- On structures that are less than 40 feet high and over ground with little or no traffic, *scaffolds* may be an access alternative. Scaffolds are used in operations in which the inspector will be at a location for a relatively long period of time.
- For structures over water, a *boat or barge* may be needed for access. Some inspection as well as photos taking can be done from a boat. A boat or barge also may be required for under water inspection.
- Bridges which are built over rivers and streams require special inspection techniques and equipment for the inspection of substructures. *Diving gear* is sometimes necessary to inspect the bridge piles and foundations. Only qualified diving personnel should perform this type of inspection.
- *Climbers* are mobile inspection platforms that "climb" steel cables. They are used for inspection of high piers or other long vertical faces of bridge members. Climbers are sometimes referred to as "spiders."
- A *float* is a wood plank work platform hung by ropes to provide access. Floats are used in operations in which the inspector will be at a location for a relatively long period of time.
- *Bosun chairs* are suspended from cables and carry one inspector. They can be raised or lowered with block and tackle devices.
- On some structures, if other methods of access are not practical, inspectors must *climb* the bridge elements. Safety awareness should be foremost in the inspector's mind when utilizing this technique.

Access Vehicles

- A *manlift* is a device with a platform or bucket capable of holding one or more inspectors. The bucket is

attached to a hydraulic boom that is mounted on a carriage. An inspector "drives" the carriage using controls in the bucket. This type of vehicle is usually not licensed for use on the highways. Some manlifts are very nimble and can operate on a variety of terrain.

- A *bucket truck* is similar to a manlift. However, it can be driven on the highway and the inspector controls the boom movement from the work platform bucket.

Under Bridge Units

Under Bridge Units are specialized machines designed to reach out and under a bridge structure while parked on the deck. These units allow access through the use of articulating booms to bridge members not normally reachable using other forms of equipment. Under Bridge Units have the following features and variations:

- Reach Capability: Varies from 30 to 60 feet
- Elevating First Boom: The first boom will reach vertically to allow the boom assemblies and platform to rotate over fences and other objects.
- Rotating Turrets: Provides horizontal movement
- Axle Locks: Allows the truck to move during inspection operations
- Telescoping Third Boom: On most machines the third boom has the capability of extending and contracting which allows for greater reach under a structure.
- Articulated fourth boom: Some units have a fourth boom that allows vertical movement under the structure. This capability is particularly useful on bridges with deep superstructure members.
- Capacity: Most units have a two or three person bucket on the end of the last boom. Weight capacity varies from 500 to 700 pounds.

Access Vehicles vs. Access Equipment

An Under Bridge Unit will be quicker than using a ladder or rigging to inspect a structure. Further more an Under Bridge Unit is mobile which means it can be moved quickly to various inspection sites. In addressing the time-saving effectiveness of a Under Bridge Unit the following questions should be answered:

- What type of vehicle is available?
- How much of the bridge can be inspected using the vehicle?
- How much of the bridge can be inspected from one setup?
- How much time does it take to inspect at each setup?
- Does the vehicle require an operator or driver other than the inspector?
- Will the use of the vehicle require special traffic control?
- Will access be possible without the use of the Under Bridge Unit?
- How much time can be saved by using an Under Bridge Unit vs. Other access equipment.
- How many bridges will the Under Bridge unit be used for?

SPECIAL EQUIPMENT TRAINING REQUIREMENTS

Some types of bridge inspection equipment require specialized training in both operation and maintenance. No person should be permitted to operate a machine without first being trained in its use. Training must be systematic and thorough, and should include these points:

- Read and be familiar with the contents of the operation and maintenance manual.
- Know the location and function of all the controls in the unit.
- Know and observe the posted capacity of the unit.
- Read the danger, warning, and caution labels that pertain to the various operation modes and conditions.
- Know how to conduct a thorough pre-operation inspection of the unit and what to look for at each checkpoint.
- Know the operation sequence of the unit.

SPECIALIZED EQUIPMENT TRAINING PROCEDURES

An individual who has been trained on one brand of equipment is not necessarily qualified to operate other machines. Machines from other manufactures vary as to capacity and operation characteristics. Training should be conducted with the entire crew that would normally operate the unit. By learning the operational aspects of the equipment together, the crew will function as a safer group. This becomes particularly important in the event of an emergency. A crew that has been trained as a group will be able to react faster and with more cooperation. Even though emergencies may never occur, the crew that has reviewed their procedures together will be best equipped to cope with all situations that may occur. The

importance of operator training can not be minimized. A good training program will result in less equipment downtime, and more importantly, will help prevent serious or disabling injuries to personnel.

SUMMARY

With bridge and highway maintenance budgets tight, managers are forced to find ways to control costs. The manager also knows that the number of bridges in their jurisdiction will not decrease and that the federal government requires that each bridge that spans over 20 feet must be inspected every two years. The manager must find ways to maximize the bridge inspection budget. It also must be kept in mind that a hands-on inspection will give the manager a more accurate assessment of the condition of the bridges in their jurisdiction. A hands-on inspection requires a greater commitment in personnel and equipment. Specialized bridge inspection equipment may be a way to maximize the inspection budget and assure that bridges are safe.

THERMOPLASTIC EQUIPMENT FOR FLEET MANAGERS

Murray Richardson
Stimsonite, Inc.

GENERAL INTENT

The purpose of this paper is to describe the current methods and possible pitfalls in selecting and bidding thermoplastic equipment for pavement striping. The specification process is, by intent, the most economical approach to purchase. However, your involvement and expertise as purchasers of mechanical equipment is needed to move towards a more productive and durable means of striping roadways.

HISTORY OF THERMOPLASTIC

Thermoplastic has been around for over 40 years and because of its minimal pollutant aspects is becoming more popular as the choice for durable pavement markings. Its longevity has been proven, and its past has only been tarnished by instructions that allowed poor equipment and installation techniques. Since those times, manufacturers have spent a great deal of time and money on improved training techniques, and technical advances in equipment for installation.

HOW DO YOU FIT INTO ALL THIS

Thermoplastic equipment, whether small or large, will probably come under your jurisdiction, whether it is maintaining the units after the purchase or purchasing the trucks used for the larger units. For example, typically the truck for a three melter thermoplastic longliner is a 35,000 GVW truck with a tag axle added. This truck will generally save you as much as $20,000 at the purchase point, due to its single axle. By adding a tag axle, the unit can handle the weight of a double axle, as well as provide greater maneuverability to expend materials by allowing the operator to lift the tag axle from the roadway.

HOW TO PREVENT GOING BACKWARD VS. FORWARD IN THE PURCHASE

As with any machine, thermoplastic equipment is designed to do a job. The best design will provide longevity but that is not always the lowest price bid. The only way to assure a good purchase is to get involved with the smallest details of the equipment. Decide for yourself what physical aspects the equipment must be provided even down to the metal thicknesses. Then, specify it in detail and accept no alternatives. Whenever possible, visit customer references provided by bidders, take photos, ask about levels of service provided *after the sale*. All of these things are difficult to put into a bid, but without an attempt to do so, your entire thermoplastic program could take a major set back.

BEWARE OF THE "NEW GUY WHO SAYS HE CAN BUILD ANYTHING"

Be cautious of bidders who have never or seldom built this equipment. They may be looking at the $200,000 price tags and bidding first, then putting together the specifics of their plan later. One bidder took a bid for two trucks and delivered the first unit over a year later. The first unit was quickly returned for additional work. The bidder appears to have wanted to start the clock on the pursuit of payment in small claims court. In the meantime, the district who purchased the trucks spent all their money on materials to be installed by the new trucks and had no money to even paint their roads with old paint machines. Everyone wants to help someone new get started, and in fact, if the new guy can do the job for less, let him. However, place penalties in your specification for late delivery, poor after the sale follow up and service, poor or no training of your new operators, etc. The greatest machine in the world is only as good as its operator.

Reputable manufacturers realize competition is good, as long as the playing field is level and rules apply equally to all players. Today, there is a need to guard against disreputable bidders who will try anything to grab the buck and leave you standing there trying to figure out what went wrong.

IMPROVE ELECTRICAL SYSTEM RELIABILITY WITH MAGNETIC CIRCUIT BREAKER SWITCH PANELS

Stuart A. Owades
Wired Rite Systems, Inc.

ABSTRACT

Electrical failures in vehicles are commonplace and are a source of serious concern for vehicle operators, maintenance personnel and fleet managers. Traditional switch panel designs utilizing switches designed for household appliances are often the source of electrical failures. Switch panels designed with magnetic circuit breakers as the circuit switching mechanisms provide a more reliable and safer method of controlling electrical apparatus. In conjunction with magnetic circuit breaker switches, solid state back lighting of switch functions provide a higher degree of reliability and performance.

This paper explores electrical problems experienced by operators and maintenance personnel in the state fleet and public works sectors. Solutions to common problems are discussed. Emphasis on magnetic circuit breaker protection and solid state back lighting as a reliable means of controlling and identifying switching circuits are discussed in detail.

INTRODUCTION

With respect to vehicle breakdowns, electrical problems rank high on the list of common occurrences. Electrical failures are typically traced to faulty apparatus, wiring harnesses, switching systems or a combination of all. Manufacturers of quality electrical apparatus used in public works vehicles generally have an excellent reliability record and provide a product that often outlasts the life of the vehicle. Wiring harnesses, if designed and constructed properly should provide years of service before replacement or overhaul is necessary. Switch panels are another story. A high quality switch panel will exceed the life of a vehicle with little or no maintenance required. Further, a carefully designed switch panel will provide excellent protection to wiring harnesses and electrical apparatus thereby providing enhanced reliability to the vehicle's electrical system. If a switch panel is improperly designed or constructed, overloads or short circuits will create failures of switch components, relays, solenoids, wiring or circuit breakers. If high current levels are present in circuits, constant overloading will fatigue components in the circuit and eventually result in circuit failures, or worse ... a fire.

Generally, switch panel types are grouped in two categories:

- Switch panels utilizing appliance control switches; and
- Switch panels utilizing magnetic circuit breakers as the switching devices.

Appliance control switch systems have been by far, the most commonly used in switch panels used in state fleet and other service vehicles. A steady move by fleet specifying engineers to design in magnetic circuit breaker switch panels has occurred in the last five years. Citing a significant improvement in reliability and performance, fleet maintenance personnel using magnetic circuit breaker switch panels are focusing on other areas of concern. The following sections will explore the differences in technologies used in the two types of switch panels.

SWITCH PANELS UTILIZING APPLIANCE CONTROL SWITCHES

Commonly identified as having "bat" type toggle levers, panels designed with appliance control switches are functionally adequate; that is, they will perform the task of opening and closing an electrical circuit. Well suited for household use where constant operation requirements and long term reliability are not as crucial as in public works vehicles, appliance switches offer perceived economical advantages over magnetic circuit breaker counterparts. Military approved versions while more robust, still do not offer the protection and long term reliability of magnetic circuit breaker switches.

A typical circuit component layout for electrical apparatus consists of a switch to open and close a circuit, a relay or solenoid to carry the load, a circuit breaker or fuse to protect the circuit, an incandescent indicator light to identify the switch function, and a number of wires connected to each component. Each component and wire connection must be considered a potential trouble point. In the event of circuit failure, trouble shooting multiple

components is time consuming and expensive. If the source of the failure is a burned wire, other wires in the same location (loom) may be burned and need replacing. Secondly, the number of components required to operate apparatus in a conventional switch system will increase the electrical resistance of the circuit enough to alter the performance of the appliance. Reliance on multiple components and wires not only presents reliability problems but increases safety risks and trouble shooting problems. Multiple connection points increase the risk of corrosion which ultimately leads to appliance failure. Lastly, original or replacement switch panel installation is both tedious and time consuming.

Appliance type switch panels commonly use incandescent indicator lamps to light each switch function. Again, while functionally adequate, several disadvantages of this technology will lead to more frequent service and replacement intervals. Typically, the indicator's function is to provide visual verification that a circuit is on and the appliance is functioning. Since an appliance switch usually powers a relay coil and not the apparatus itself, it does not know when an overload has occurred. As a consequence, the indicator light which receives its power from the switch continues to operate even when a fault has occurred. There is no provision to visually alert the operator of a fault. Incandescent indicators use the same light source found in the common household light bulb. The light emitting component (tungsten filament) is fragile and is susceptible to failure when vibration is encountered. In domestic use, rarely does a light bulb encounter the vibration and shock conditions that are every day occurrences in service vehicles. While evolutionary design improvements have led to more reliable performance, shock sensitivity still remains a serious concern. Life expectancy of incandescent lamps are dramatically less than solid state counterparts. In best case environments incandescent lamps have a life expectancy of approximately 15,000 to 20,000 hours. A typical vehicle will need indicators replaced every two to three years if vibration or heat related problems do not create a failure earlier in the life cycle.

SWITCH PANELS UTILIZING MAGNETIC CIRCUIT BREAKER SWITCHES

Magnetic circuit breaker switches offer considerable advantages over appliance switch counterparts. Widely used in computer and industrial controller applications, magnetic circuit breakers offer the best possible protection for any application requiring highly reliable circuit protection. With state of the art circuit protection built into the switch, no longer does an installer need to wire a complement of relays, solenoids or circuit breakers for each circuit into the vehicle. Modern switch panels incorporating magnetic circuit breaker switches allow the installer to bring one wire in from the positive side of the battery to a common bus bar on the back of the panel. Installation is completed by routing one wire from each switch function to its designated apparatus. Installation and trouble shooting time, if required, is significantly reduced.

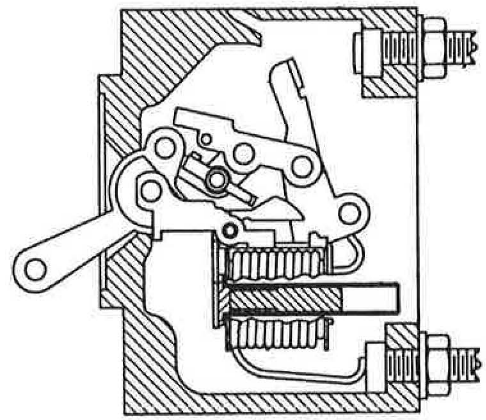

FIGURE 1 Cross section of magnetic circuit breaker.

Perhaps the most important advantage of magnetic circuit breaker switches is their method of circuit protection. Magnetic circuit breaker switches open automatically under overload conditions, see Figure 1. Unlike thermal circuit breakers that use bi-metallic strips to sense thermal changes to trip, magnetic circuit breakers utilize a magnetic time delay system where hydraulic sensing components react only to changes of current in the circuit being protected. As a result, they are considered temperature stable and react instantly to overloads. Temperature stability is critical as magnetic circuit breakers will perform reliably when a vehicle is operated in either cold or warm temperature extremes ... not so with thermal circuit breakers or fuses. Further, magnetic circuit breakers have no "warm-up" period to slow down their response to overloads nor is there a "cool-down" period after overload before they reset.

A highly efficient circuit tripping system provides excellent protection. Mechanically speaking, the tripping mechanism consists of a current sensing coil connected in series with a set of contacts, see Figure 2. As the normal operating current flows through the coil, a magnetic field is created around the coil. When current flow increases, the magnetic field also increases drawing a magnetic core inside the coil toward a set of contacts. When the core is fully energized an armature is attracted to the core,

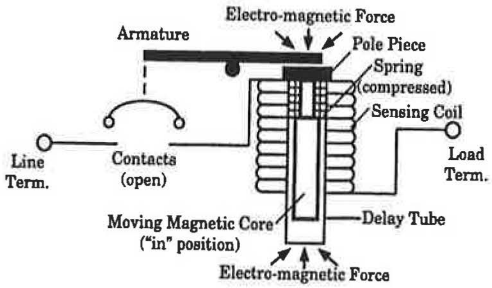

FIGURE 2 Tripping mechanism, magnetic circuit breaker.

unlatching a tripping mechanism, thereby opening the contacts. This process is so efficient that under short circuit conditions the response time to open the circuit is milliseconds. Magnetic circuit breakers are designed to operate up to rated current levels and contain a delay circuit that will allow certain current surges to occur without causing "nuisance tripping." For safety concerns, a trip free mechanism makes it impossible to manually hold the contacts closed during overcurrent or fault conditions. Switches are available in current ratings of 10-50 amps. Actuation is single pole, single throw only.

Dual stage, solid state LED (Light Emitting Diode) back lighting, working in tandem with magnetic circuit breaker switches are a highly effective means of back lighting switch functions. Typical of solid state components, LED's are extremely rugged and have lifetimes exceeding 100,000 hours of operation. Switch panels with LED's mounted into circuit boards should provide trouble free operation beyond the life of the vehicle. Innovative design features allow the indicator system to become a complete visual verification and fault indicating device. Fault indication is a result of the back lighting system wired directly to the magnetic circuit breaker switch. When a fault is detected the circuit breaker trips, the switch actuator moves to the off position killing power to the indicator.

A dual intensity feature allows the vehicle operator to read the switch function when the switch is off and the ignition is on. When the switch is turned on, the intensity of the back lit indicator becomes ten times brighter giving instant verification of a closed circuit. When several switches are mounted in tandem, this feature easily allows the vehicle operator to determine which switches are on.

CONCLUSION

The performance of magnetic circuit breaker switch panels currently used by state fleet and public works organizations has exceeded expectations. Use of this system has dramatically reduced the occurrences of electrical faults in vehicles. Combining durability and safety, fleets are now assured of having the best possible electrical protection available. Vehicles will have fewer maintenance calls and operators are able to drive vehicles with renewed confidence. As a result of performance and reliability successes, an unprecedented lifetime warranty offered by switch panel manufacturers demonstrates the confidence placed in this technology.

A SIMPLIFIED HEAVY-DUTY SAND SPREADER, PHASE I—DESIGN CONCEPT

Samuel Fields
Oregon Department of Transportation

INTRODUCTION

Driving a heavily-loaded tandem-axle truck over a mountain pass on an icy road in a blizzard is no easy chore. Adding the simultaneous tasks of plowing snow and spreading sand makes it even more difficult. To increase the comfort and safety of operators, Oregon Department of Transportation (ODOT) has in recent years purchased trucks with enhanced rear suspensions. These trucks have proven their worth on the road, but increased suspension travel has resulted in greater bed height, which in turn has caused some difficulties in loading sand. A lack of desire to go back to our old truck suspensions, along with a general dissatisfaction with some of our sand spreaders, led us to investigate the possibility of solving the loading problem, as well as some other problems, by changing the sander design.

RECOGNIZING THE PROBLEM

Three things cause sand loading problems for ODOT. The first is bed height. Another is loaders with limited reach, which includes most currently available articulated loaders and tool carriers. The first two problems would not be so noticeable were it not for the third problem, which is the gratings, or "grizzlies," on top of the sander. The grizzlies do not allow the loader bucket to drop down and dump the load into the sander without some persuasion. Loader operators commonly hammer the lip of the loader bucket on the grizzlies to shake the load into the sander. This results in a long loading cycle and damage to the grizzlies.

The purpose of the grizzlies is to prevent damage to the sander conveyor from large stones and to prevent such stones from being deposited on the highway by the sand spreader. The grizzlies are sloped upward to allow stones to fall off after the smaller material has fallen into the sand spreader. This slope makes the sander even higher and loading even more difficult. Some maintenance units have tried ramps to increase the loader height, while others have experimented with pits to lower the sander height, neither of which has proven completely satisfactory. Other units have requested that our office design extensions for the loader arms, which does not seem to be a reasonable solution. Yet others have asked for loaders with more reach. More reach would be a solution except that those loaders with sufficient reach tend to be so large and heavy as to create a transportability problem. After considerable study it seemed that the best solution would be to remove the grizzlies and solve the large stone problem by some other means.

Other problems with sand spreaders have been tunneling, stalling, excessive downtime, and the difficulty of unloading the sand spreader in the event of a failure. A relatively minor problem associated with unloading is the difficulty of removing stones and other debris from the sander should it somehow get past the grizzlies.

Tunneling occurs more often with auger conveyors than with chain types. The auger bores a nice round hole in the sand and tends to compact the walls of the tunnel so that the sand doesn't cave in and get transported by the auger. Chain conveyors dig a wide rectangular hole in the sand, which caves much easier than a round hole, so that chain conveyors tunnel only with sticky or semi-frozen material. Both the width and the speed of the conveyor affect tunneling. A wide slow conveyor will tend not to tunnel, whereas a narrow fast conveyor will tunnel easily.

Stalling is affected by the configuration, available power and the sanding material. Given the same available power, a chain sander conveyor will stall quicker than an auger conveyor. Any conveyor will stall with frozen material. Sticky or semi-frozen material might more easily be expelled by an auger conveyor were it not for the tunneling problem.

Downtime is a major problem with slip-in sanders regardless of the type of conveyor. The experience at ODOT has been that presently available auger sanders are less reliable than those with chain conveyors. This might be at least partly caused by ODOT's use of volcanic ash as sanding material and partly due to auger speed. Volcanic ash abrades chains and augers alike, but auger pipe walls seem to be especially vulnerable, especially so since they are usually only 6 millimeters thick.

PROPOSED SOLUTION

ODOT engineers recognized that sand spreaders evolved from agricultural spreaders designed for fertilizer, manure,

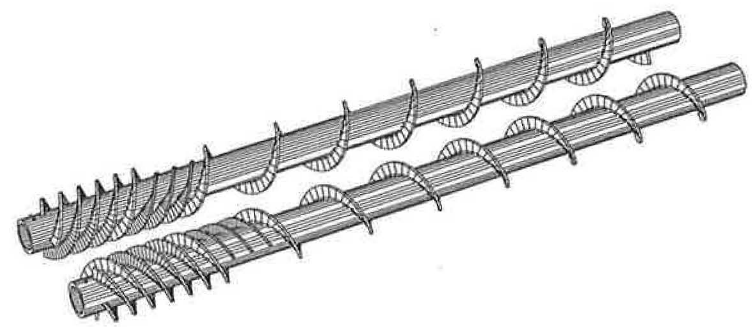

FIGURE 1 Dual augers.

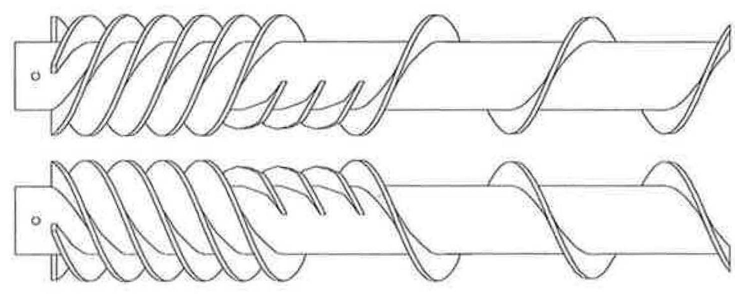

FIGURE 2 Rock rejectors.

or lime and not specifically for heavy, abrasive materials used for traction enhancement. Augers present the best potential for conveyor efficiency if tunneling and wear problems can be solved. Augers presently used in sanders were designed for feed mixers instead of volcanic ash. It was necessary to approach auger design with volcanic ash as the intended product to be transported. This required drastic changes in materials and configuration. Tunneling required either an anti-tunneling agitator, a shaker, or a wider tunnel. The choice was creating a wider tunnel by using dual counter-rotating augers.

Wear is a universal concern for engineers, and can be reduced by lubrication, lower speeds, lighter loading, and more resistant materials. In the case of the dual auger sander, lower speeds are possible by using two augers instead of one, and by increasing the pitch of the flights. The auger pipes are Schedule 160 steel pipe with a nominal outside diameter of 168 millimeters and a nominal wall thickness of 18 millimeters. The flights have a thickness of 13 millimeters and a height of 64 millimeters. Flight material is Scandia or Formalloy steel with minimum indicated hardness of 4900 newtons per square millimeter measured by the Brinell method. Greater pipe wall thickness allows better flight weld penetration and also prevents excessive pipe flexing. Flight pitch has been increased to 381 millimeters to permit a further decrease in speed.

The two augers are set on 356 millimeter centers and are counter-rotating. The present design calls for a single 918 cubic centimeter hydraulic gear motor producing 1,512 newton-meters torque. The augers are geared together and turn at a nominal 15 revolutions per minute. An open question at this time is whether to continue with a single motor and synchronized augurs, or to change to two motors and a more random pattern of rotation.

At the discharge end of each auger three short flights are placed between the regular flights, with a gradual ramp up to full height, see Figures 1 and 2. The augers are placed so that each auger discharges sand through a hardened steel hoop. This is the rock rejector feature of the sander, which allows the sander to be used without grizzlies. A specially designed tailgate allows rocks and

other debris to be dumped without removing the sander. The spinner chute is made from rubber belting material so that it can flex during dumping.

The ability to raise the truck bed while the sander is installed is an important feature of this design. In addition to the flexible spinner chute, the sander is equipped with an exhaust "hat" which fits over the exhaust pipe of the truck much in the same manner as an aircraft in-flight refueling nozzle. This automatically connects and disconnects the sander heater as the bed is lowered and raised. The a specially designed rain cap is opened and closed by the sander exhaust receiver.

The augers are supported at the front inside of the sander box by a bearing box or "hot box" which also serves as a junction for the truck exhaust. The exhaust is routed through channels underneath the augers to aid in heating the sand. The channels form part of the skeletal structure of the sander and provide some of the required rigidity. The hot box is bolted to the truck bed through a cross member.

The most significant departure from previous sander design is in not attempting to contain all of the sand within the sander itself. Conventional philosophy has centered in spreading all of the sand contained in the truck before reloading. ODOT believes that this is not necessary and leads to excessive cost and complexity. By simply filling the bed with sand and spreading all the sand that the augers will discharge, it is possible to spread as much sand as a carefully designed conventional slip-in sander will spread. If, near the end of a sanding patrol, the operator were to raise the bed and concentrate the remaining sand towards the rear of the bed, it is possible to spread even more sand than a conventional sander. This should be possible with this design. Therefore, ODOT proposes to eliminate the sides, front and back of the sander and install only the working portion plus a special tailgate.

Eliminating the sheet metal and using heavy duty mechanical components should increase the reliability and decrease downtime of sanders. In addition, the ability to apply an extra portion of sand will increase the productivity. ODOT intends to continue with this project, and measure the costs and benefits next sanding season.

ACKNOWLEDGMENTS

The author wishes to acknowledge the contributions of Dick Berkey of ODOT and Gordon Stuller of Austin Mac, Inc. Special thanks are due to Tom Starr of ODOT, who has done most of the work on this project.

TOTAL COST EQUIPMENT PURCHASING

H. Lee Hax
South Carolina Department of Transportation

SUMMARY

The South Carolina Department of Transportation's Supply and Equipment Office was asked to review the purchasing of equipment using the Total Cost Method and to compare the results to the Department's Low Bid Method for a motor grader. An analysis of both methods using actual costs shows that the Department's method is the more economical of the two buying procedures.

TOTAL COST STUDY

Project. Evaluate the feasibility of utilizing the Total Cost Method (TCM) of purchasing equipment.

Background. The TCM was developed to assist buyers in determining the total costs incurred during the life of a piece of equipment. The TCM is promoted by several manufacturers in the construction equipment industry. While frequently used in the private sector, the TCM poses problems in the public sector where low initial or bid cost based on specifications is required for equipment acquisition.

Total Cost Method. The TCM consists of three parts. These are:

- Purchase cost of new equipment.
- A guarantee by the vendor to repurchase the equipment for a given amount at a specific future date.
- An optional guarantee that repair costs will not exceed a specific amount during a specific period

The TCM is based on the concept that the lowest cost to the purchaser is the cost of the first item less the cost of the second item. This concept is potentially valid. However, depending on several factors, use of this purchase concept may not be the most economical method to purchase equipment. At the end of the contract period, the user sells the equipment back to the vendor at the price quoted when the equipment was purchased. The user may then purchase a new piece of equipment. It should be noted that the manufacturer does not guarantee that this buy back will occur. Manufacturers do not bid the equipment themselves but rely on their dealers to do the bidding and make all guarantees. Any TCM should be used with a bonded dealer to insure payment.

PURCHASE METHOD COMPARISON

Table I contains a comparison of the two methods over five, 10, 15 and 20 year periods. It should be noted that the comparison does not include maintenance costs.

The major differences between the two methods are that the TCM does not account for time value of money and for opportunity costs. The time value of money suggests that money received today is worth something different than money received in the future. Although future inflation is not known, an estimate should be included to determine the future value of money. Opportunity costs, the second adjustment, represents the potential interest that could have been earned on the excess money spent. For example, the difference in price for the units in this case study is $69, 271. If this amount were invested at 8% annual interest, a compounded total of approximately $30,000 would be earned in five years. Viewed another way, the $5,540 earned in interest (8% of $69,271) each year could be used for equipment maintenance—while still retaining the $69,271 principal. This would apply through all twenty years of the study.

ADVANTAGES AND DISADVANTAGES OF USING THE TOTAL COST METHOD

Advantages

- Predetermined ownership cost for budgeting purposes. Depreciation is known in advance.
- Predetermined residual value (resale value) of equipment.
- Maximum repair costs are guaranteed for a specified period by a fixed ceiling on costs (optional bid item).
- Monthly or annual maintenance and repair costs are known (optional bid item).
- Forced preventive maintenance schedule.

TABLE 1 PURCHASING METHOD COMPARISON*

Example Equipment	Total Cost Method Caterpillar 12G	Low Bid Method Champion 710A
Unit Sold in 5 Years		
Cash Price	$ 132,000	$ 73,361
Sales Tax	6,300	3,668
Buy Back	(73,000)	0
Total Cost	65,300	77,029
** Future Value (Single Payment)	0	(30,013)
Net Owning Cost (5 Years)	**$ 65,300**	**$ 47,016**
Unit Sold in 10 Years		
New Owning Cost (5 Years)	$ 59,300	$ 77,029
Cash Price Replacement (Incl. 7.5% est. incr.)	148,672	0
Buy back (est.)	(78,475)	0
Total Cost	125,672	77,029
** Future Value (Single Payment)	0	(74,728)
Net Owning Cost (10 Years)	**$ 129,497**	**$ 2,682**
Unit Sold in 15 Years		
Net Owning Cost (10 Years)	$ 129,497	$ 77,029
Cash Price Replacement (Incl. 15% est. incr.)	159,045	0
Buy back (est.)	(83,950)	0
Total Cost	204,592	77,029
** Future Value (Single Payment)	0	$ (141,347)
Net Owning Cost (15 Years)	**$ 204,592**	**$ (64,318)**
Unit Sold in 20 Years		
Net Owning Cost (15 Years)	$ 204,592	$ 77,029
Cash Price Replacement (Incl. 22.5% est. incr.)	169,417	0
Buy Back (est.)	(89,425)	(2,923)
Total Cost		
** Future Value (Single Payment)	0	(240,599)
Net Owing Cost (20 Years)	**$ 284,584**	**$ (166,493)**

* The Total Cost/Low Bid Comparison does not include maintenance costs.
** Future value of a single present payment program computed using 8% interest.

- Includes penalty clauses for parts delays or delays in service completion dates.
- Reduced downtime based on the theory that equipment will be replaced on a more frequent basis.

Disadvantages

- No allowance for cycles of Agency budget allocations (surplus or deficit) and availability of funding. In today's economy there is no guarantee money will be

available to replace buy back equipment when contract ends.

- The TCM does not take into account the future value of a single present payment. For an Agency, the present value represents the difference in the purchase cost between the TCM and the LBM.
- "Locked in" on a set replacement schedule to secure the guaranteed resale price.
- Favors large firms over small, disadvantaged, or minority-owned businesses due to large amount of capital outlay required to participate.
- Typically higher initial purchase price.
- Depends on viability of bidder to fulfill obligations. Equipment manufacturer not liable.
- Bidders must agree to post a performance bond in the amount of buy back.
- Strict maintenance schedule and/or reporting schedule which, if not followed, may void contract.
- Resale agreement is subject to interpretation pertaining to records and maintenance at the time of buy back.
- If an agency cannot recall their equipment within five years, buy back option is forfeited.

SURVEY OF STATE DOTs

A recent survey of state DOTs found that Arkansas uses TCM to purchase tractors with a one year buy back. The states of Florida, Georgia, Kentucky, Mississippi, North Carolina, Virginia and West Virginia do not use TCM. The states of South Dakota and Texas have had laws prohibiting the use of TCM.

CONCLUSION

The main advantage of using the TCM is that for budgeting purposes there are predetermined equipment and maintenance costs. The disadvantages, however, are numerous. There is no allowance for cycles in an Agency's budget allocations and availability of funding. The TCM promotes buy backs which eliminates some bidders on equipment. The manufacturer does not guarantee the buy back, and resale agreements are subject to interpretation pertaining to records and maintenance at the time of sale. If the agency does not return equipment, the buy back is void.

The future value of a single present payment based on the difference in total of buy back versus LBM clearly indicates the cost advantage to the LBM. The LBM using SCDOT specifications, does not reduce the standards of any equipment purchased, these include product warranty, downtime, safety, and Department image.

LIFE CYCLE COSTING . . . A MANUFACTURER'S GENERAL PERSPECTIVE

Coke Mattingly
Caterpillar Inc.

One of the most important jobs of a governmental official is to justifiably allocate public funds for equipment procurement. This requires the balancing act of equipment needs, budget constraints, and taxpayer's scrutiny. Each of these forces plays a powerful role in purchasing equipment. It's not an easy job. It demands selecting and substantiating one product over another. The ultimate goal is to make the right decision offering the best return for the public.

"Life Cycle Costing" (LCC) has become an effective method of equipment acquisition. This concept is based on understanding that the price of the machine is not stagnant and continues to grow after the initial purchase and throughout the period of ownership. These added expenses are many times unknown and can place a heavy burden on cash flow or budget controls. Operating expenses, maintenance and downtime, plus productivity and resale value must be part of the total equation to fully understand the actual price of the equipment. LCC puts the ability to control these elements in the hands of the buying agency. Having the ability to predetermine and limit equipment costs, plus a guaranteed resale value help minimize financial and political risk and maximize return on capital invested in equipment. This is the goal of a public official.

Through LCC bids the buying agency can tailor a bid specification unique to their operational needs. LCC contracts can be multifaceted and include guarantees on repair and labor costs, uptime and parts availability, plus guaranteed buy backs. Contracts could be a lease or outright purchases, and range from 1 year to 7 years. Once these specifications have been developed by the buying agency, based on its needs and desires, it is up to the supplier to review the specifications, evaluate its product and determine its capabilities to provide the services the agency has requested. In other words, it's up to the manufacturer and its distribution network to develop the product and capability to provide the buying agent the best bottom line.

This causes several challenges for the manufacturer. The first requirement for any manufacturer is to provide a machine that is within the customer's basic specifications. This would include type of unit, horsepower and weight or other general requirements. At this point, if it's a low bid situation, any unit meeting these specifications would qualify for the bid, regardless of its performance characteristics, reliability, durability or resale value. But, if the bid is based upon performance guarantees such as LCC, this unit may or may not qualify for the bid.

Because LCC is based upon machine performance and value, the manufacturer has to face many engineering and manufacturing considerations. First, if the unit is not designed or produced to support contractual guarantees, it becomes economically prohibitive to offer this value to the buying agency. Each process of equipment design and quality must be reviewed on its ability to contribute to the performance of the unit over a period of time. The risk of short and long term performance lies heavily on the manufacturer's engineering and design philosophy. It forces manufacturers to evaluate their products on the basis of total net cost to the user.

Once the product is produced, the focus centers on the relationship between the manufacturer and the dealer network. It is vitally important the dealer and manufacturer share the same philosophy concerning product support and customer satisfaction. The equipment dealer is the foundation for product support. The dealership has to be financially sound, reliable and committed to have the capability of offering LCC type of sales contracts.

If the LCC equipment bid has limits on repair and labor costs and a maintenance contract, it is necessary dealers have fully trained mechanics with the appropriate diagnostic tools to insure service work is done correctly, promptly and efficiently. Equally important is the dealer's commitment to parts inventory and good cost controls to maintain an efficient sound operation. In simple terms, LCC contracts place the burden on the dealers to be efficient and responsive. The buyer benefits from this burden.

Buyback guarantees require a dealer to make an up front commitment to the purchasing agent. They have to understand the used equipment market. Knowing the future value of the product is essential to this type of bid. Also, the dealer needs to be bonded to protect the governmental agency.

Finally, the dealer has to be flexible. LCC bid specifications can have many different conditions and clauses. The dealer has to be able to meet each of the requirements of the bid. This may require commitments the dealer has not done before. However, the dealer has to ultimately determine whether it can meet the obligations of the specifications.

The job of the public official is to make the right decision when purchasing equipment. It requires an evaluation of the product and its return to the agency. LCC provides a total picture of what the product is worth to the buyer over the ownership and reduces the risks of making a poor decision, because making the wrong decision could be very costly in terms of unexpected expenses in repairs and downtime. Making the wrong decision also can create havoc with the agency's budget and cash flow. The manufacturer also has to make the right decisions in developing product quality. The wrong decision for the manufacturer can be very costly in terms of lost sales. The goal of any manufacturer should be to provide customer satisfaction through performance and value over the life of ownership. It is up to the buyer to demand what that level of value should be.

TIRE RECAP PROGRAM

John M. Burns, Jr.
North Carolina Department of Transportation

Reasons for tire recap programs include reduced cost of fleet operation, conservation of natural resources and accommodation of environmental concerns. In the area of economy, a recapped tire costs North Carolina Department of Transportation (NCDOT) 50 to 70 percent less than a new tire. Such savings make it easier to afford the very best in tire casings with associated fuel savings. NCDOT rubber compound is "tough" with consequent longer tread life than that experienced with new tires. An example of one test among several that demonstrated this characteristic is found in table (1). Additionally, a recapped casing is one whose disposal can be deferred with consequent savings.

Safety considerations for recaps are equal to or greater than for new tires. Tires are subject to "infant mortality," where casing failures due to manufacture usually occur early in the tire's life. Recapped tires use proven casings and bypass these infrequent but predictable failures. Tread failures in recapped tires are essentially preventable. They are due to tread separation associated with leaking air from casing pinholes that can be found and repaired, given appropriate processing prior to recapping. Scrap rubber along highways is often attributed to recap process failures. The material is not there because of a peeled retread but rather from tire abuse whether new or recap. Overloading, under inflation, mismatch of dual tires (in diameter) all contribute to tire abuse which causes tires to come apart. Look for wire; if it is there, you are seeing part of the tire casing and the problem was misuse rather than associated with recapping.

A tire recap program supports conservation of natural resources. An average truck tire requires 22 gallons of petroleum and significant energy for its manufacture. A recap requires 7 gallons of petroleum for its manufacture. Recapping casings rather than replacing them saves 15 gallons of petroleum per recap.[1] From an environmental standpoint, a recapped tire is one where its disposal as solid waste is deferred with reduced requirement for landfill.

Fleets anticipating a new or significantly expanded tire recapping program will find there are prerequisites in the planning phase that will improve the success of its implementation. Essential to success is an education program. There is resistance to recaps that includes the impression that recaps are unsafe. Additionally, the adverse impact associated with "rubber on the road" must be overcome and the importance of a tire pressure maintenance program emphasized.

Introduction of an all steel belted tire program prior to a fleet-wide recapping program will maximize the program effectiveness. Though more expensive than bias ply tires, stronger casings allow more recaps per casing thereby reducing total cost. On and off road steel belted radial tires result in fuel savings. Decisions on customized tread design, such as bi-directional treads for motor graders, are necessary to allow proper preparation by recap suppliers. The mentioned example allows reduction in inventories.

Recappers are, unfortunately, not all created as equals. The success in seeking the best recap supplier available through tight specifications will make or break a recap program. NCDOT recapper, White's Tire Company of Wilson, North Carolina, is one of the largest in the world. Our program experiences less than one half of one percent returns for warranty adjustment. The national average for returns is three to four percent with up to six percent experienced in some geographic locations.

Continuing program improvement is necessary to stay with the state of the art. Improvements generally originate in Europe and are imported slowly. Evaluation of possible alternative processes and materials will result in the most effective program practical within available resources. After testing and costing against alternatives, intended changes must be incorporated in specifications. Thereby, the supplier remains competitive while improving product and subsequently, upon contract renewal a level bidding field for all suppliers is ensured. Most improvements in quality carry with them significant costs in capital equipment and a fast way to make an ideal supplier lose out to their competition is for them to cost a level of quality, that they understand is required from experience, that is not identified to all by specification.

Examples of evaluations that were subsequently included in NCDOT's specifications are reviewed in the following paragraph

A change to the rubber compound used in recapping was tested in a head to head evaluation. As a result a unique compound was specified that resulted in increased recap life. Inclusion of rubber dust resulting from casing preparation in rubber compounds was evaluated as a cost savings to the recapper that would be passed on to the customer. Tests showed that inclusion of eight percent rubber dust had no adverse impact on mileage. Specifications were made permissive on this point. A change from precured "top cap" to a mold cured process on radial casings resulted in this

TABLE 1 MILEAGE EXPERIENCE* FOR NEW TIRES VERSUS RECAPS

Tire Type	Tread Depth in 1/32 inch			Wear per 100 hrs.
	No. 1	No. 2	No. 3	
East Coast Division - 936 hrs. between March 23, 1993 and June 24, 1994				
New Tire	15	12	9	0.0641
Recap Tire	20	17	15	0.0470
Piedmont Division - 687 hrs. between April 2, 1993 and March 9, 1994.				
New Tires	20	18	18	0.0582
Recap Tires	25	25	24	0.0320
Mountain Division - 1,153 hrs. between April 6, 1993 and May 18, 1994.				
New Tires	6	8	8	0.0641
Recap Tires	9	10	10	0.0581
	Average Wear per 100 hrs.		New Tires	0.0621
			Recap Tires	0.0457
Conclusion: Recap tread life exceeds new tire tread life by approximately 25%				

*Motor Grader Tires 1400R x 24. Three new tires on one side and three recaps on the other with rotation every 200 operating hours. All tires started with one inch tread depth.

Reference

1. Tire Retread Information Bureau, 900 Weldon Grove, Pacific Grove, CA 93950.

becoming the preferred method of recapping. Specifications require capability for both on the part of the suppliers. New techniques for testing casing strength and identifying small air leaks were identified by the supplier. After evaluating the new processes against present methods, the increased expense was deemed the economic choice and specifications were changed.

The recap process that results in the high quality product enjoyed by NCDOT is outlined in the following:

- Casings are screened at shops generating casings to ensure that casings are not broken and that they are within warranty period.
- Casings are picked up on site by the recapper at least biweekly if required to support inventory. Casings in excess of local need are transferred to other shops or sold through closed bid. Recapper representative screens tires along with NCDOT representative to ensure that casings appropriate for recapping are transported.
- The first step in the process is provision of specified rubber compounds. Our recapper blends the compound required and produces precured material in necessary treads and uncured rubber in appropriate extrusion forms, rubber "roping," "tread belt" rolls, side wall veneer rolls and raw rubber void repair material.
- The first step for the casing is a high pressure casing strength test to eliminate those casings that have operated at very low pressures or otherwise suffered damage.
- The next step provides a visual internal and external expanded casing inspection.
- Nail hole detection is performed by two methods. High voltage is applied to the inside of the casing. If an irregularity (hole or breakdown in rubber) is present, it will be evidenced by an arc jumping to the outside "ground." The second method involves introducing a fluorescent gas under pressure into the tire casing. Under ultraviolet light the escaping gas is visible and the hole is marked.
- After additional internal and external examination and repair of nail holes, the tires go to the buffing stations.
- Buffing removes old tread and prepares a buffed and balanced tire casing. Buffing proceeds from bead to bead for tires receiving new side wall veneer.
- After buffing, rock drilled or cut casings are prepared by grinding out damaged areas. An adhesive is sprayed on at this station.
- The next station rechecks for damaged areas requiring grinding, and then fills grinding and ground out voids with raw rubber. The material is smoothed with a "hot knife."
- A second application of adhesive is sprayed on at the next station and then the casing is passed to the recap operation.
- Extruded tread belt material and side wall veneer (for bead to bead) is applied to the casing. The built up casing is passed to the molds.
- Casings are placed in the molds and pressurized. The heat curing results in a molded tread and side casing embossing (if bead to bead recapping).
- The final production line station includes trimming, a high pressure test and a spreader inspection of the casing inside and outside.

The completed casings are staged for delivery. Pickup and delivery is scheduled to all equipment shops every two weeks

Financial benefits of the NCDOT tire recapping program are significant and growing. In fiscal year 1994-95 the program saved $816,800 by use of recapped tires instead of new tires in the same application. Experience has shown that tires recapped with NCDOT's rubber compound out wear new tires by approximately 25 percent, all else being equal. A spin off benefit is that a recapped tire is a tire whose disposal has been deferred with associated savings in handling, landfill tipping fees and expense of casing disposal through other alternatives. These reductions in operating expense are not included in the specific dollar savings addressed above.

From a conservation standpoint, 7,493 tires recapped saved 112,395 gallons of petroleum had they all been truck tires. Actually, almost 1,000 tires were motor grader, loader, and tractor tires with significantly higher petroleum savings.

In sum, the NCDOT tire recapping program has been a resounding success story and emphasis on a specific tire maintenance program, that includes heavy dependence on recapping, is recommended to all large fleet owners.

REFERENCE

1. Tire Retread Information Bureau, 900 Weldon Grove, Pacific Grove, CA 93950.

CONCEPTUALIZATION OF THE FUTURE HIGHWAY MAINTENANCE VEHICLE

Leland D. Smithson
Iowa Department of Transportation, and
Duane E. Smith
Iowa State University

ABSTRACT

The universal challenges facing governmental agencies today are to increase productivity and quality, and to be more environmentally friendly. This comes at a time when road users are requiring more independence and an increased level of service for winter driving. The snow and ice control operations provide a situation that will benefit from utilization of advanced technology. In recognition of this potential, the state DOTs of Iowa, Michigan, and Minnesota have formed a consortium to support a project that will define vehicle and equipment requirements, develop and evaluate a prototype vehicle, and produce vehicles for fleet evaluation. The Center for Transportation Research and Education, a center of Iowa State University, is providing staff support to the project. A key element of this project is the inclusion of private sector partners in the consortium.

The approach that is being pursued is defined in three phases: 1) description of the functions and a financial evaluation; 2) prototype development and evaluation; and 3) a comprehensive fleet evaluation. The first phase will identify concepts, define the functional requirements, develop high level designs, and perform a cost effectiveness analysis. During the second phase of the project, manufacturers, systems integrators, and the consortium will develop one prototype concept vehicle (or possibly one for each consortium state) which will be evaluated against the performance criteria. In phase three, several vehicles will be built for fleet evaluation. It is likely that these vehicles will be standard design maintenance vehicles with advanced technology systems incorporated into them.

The project schedule is driven by the winter months and the need to have the prototype and fleet vehicles available for winter maintenance operations evaluations. The schedule is to have a prototype vehicle ready for testing during the winter of 1996-1997, and fleet vehicles available for the winter of 1997-1998.

INTRODUCTION

Some of the universal challenges facing governmental agencies today are to increase productivity and quality, and to be more environmentally friendly. These challenges are of major importance to three-quarters of the state's department of transportation (DOT) who must face the perils of winter as they strive to provide around the clock mobility to the road user. Snow and ice control during winter storms presents highly complex tasks and long, stress-filled hours for equipment operators and their supervisors. Continued cutbacks in DOT staffs dictate that (now) one equipment operator be able to drive a snow plow truck and manage all its ancillary equipment, whereas in the past there were two operators in the truck. These staff reductions come at a time when road users are requiring more independence, through greater mobility, and an increased level of service for winter driving. Reliable, just-in-time deliveries are the backbone of most states' economic well being, and are essential in the ability to attract new industry.

Therefore, snow and ice control operations provide an environment that will benefit greatly from improvements in state of the art vehicle navigation systems, on-board computer applications, enhanced safety systems, and improved equipment operator efficiency. Advanced vehicle navigation systems can make equipment operations safer during times of poor visibility, often found during winter storms. Sensors and automated attachment controls can improve operator efficiencies: for example, the equipment operator could automatically set the most efficient underbody snowplow blade angle and down pressure by utilizing onboard computers and sensors. Computers can record and analyze roadway surface temperature and friction values to determine optimal timing and application rates of chemicals and abrasives. Automatic global positioning vehicle location systems can track and record work progress. Computers, video cameras, and sensors can monitor vital signs of the major vehicle components and the ancillary snowplow equipment. By warning operators of abnormal conditions they can help avoid costly and untimely breakdowns.

THE CONSORTIUM

In recognition of the potential that exists when utilizing advanced technologies for highway maintenance activities, this project has been initiated to define the vehicle and equipment requirements, to develop and evaluate a

prototype vehicle, and to produce vehicles for fleet applications. To initially focus on the maintenance operations that are most under public observation, the winter snow and ice operations will receive the first consideration for technology applications. At the same time, the research team realizes that many of the technologies adopted will transcend the entire maintenance operations spectrum. The conceptualization and design of the advanced highway maintenance vehicle is being supported in phase one through a consortium of three snowbelt state DOTs. The state DOTs of Iowa, Michigan, and Minnesota all have reputations for embracing innovation in maintenance management, maintenance operations practices, and research. Therefore, they form the core and founding membership of the consortium. The Center for Transportation Research and Education (CTRE), a center of Iowa State University, is providing staff support to the consortium. The project definition and objectives are parallel to the interests and experience of the CTRE support staff. A key element of this project is the inclusion of private sector partners into the consortium. Private sector partners bring many assets to the project including staff with specialized expertise, business connections, manufacturing facilities, and the potential to participate in the funding and production of both prototype and fleet vehicles. Private sector partners and additional public sector members will be invited to join the consortium. The various consortium relationships are identified as:

- Initial Membership
  - Iowa Department of Transportation
  - Michigan Department of Transportation
  - Minnesota Department of Transportation
  - Center for Transportation Research and Education—staff to consortium
- Other Potential Public Sector Participants or Observers
  - Federal Highway Administration
  - Other state departments of transportation
  - Public works agencies
  - Representative local government agencies
- Potential Private Sector Participants
  - Vehicle manufacturers
  - Vehicle component manufacturers
  - On board vehicle tracking and communications manufacturers
  - Technology manufacturers and integrators

THREE PHASE RESEARCH PLAN

The scope and breadth of a research project of this nature is difficult to totally define at the conception and initialization stages. There are many developments that will occur when technology options are evaluated and properly categorized as to their value and feasibility for the project. The inclusion of private sector partners adds a dimension that can initially only be imagined. The approach that is being pursued is defined in three phases with the first phase having the most clarity of scope and the following phases being more broadly defined due to their reliance on phase one results. The three phases are: 1) description of the functions and a financial evaluation; 2) prototype development and evaluation and; 3) a comprehensive (fleet) evaluation. At the time of the Eleventh Equipment Management Workshop, the project is in phase one and the writing style will document the progress to date as well as describe tasks that have been identified but not yet accomplished.

Phase I: Description of Functions and Financial Analysis

The first phase will identify concepts, define the functional requirements, form public and private partnerships, develop high level designs, and perform a cost effectiveness analysis for a highway maintenance concept vehicle. As an over-arching activity, during Phase I, funding opportunities to carry the project into prototyping and fleet development will be investigated and promoted.

The process of identifying the requirements of this concept maintenance vehicle is very similar to the product development process used in the manufacturing community. This will be the first time that some of the technologies have been brought together to meet the needs of the maintenance equipment operator and to provide the functions required for roadway maintenance activities. Because the introduction of new technologies into highway maintenance vehicles is similar to new product development, the process that will be utilized is one used in the private sector called "Quality Function Deployment" or "QFD." The process requires customer input before the product is designed and manufactured. The key is to identify the customer requirements "in their own words" and not in the words of a marketer or an engineer. Once the customer requirements have been defined in QFD, and documented using the House of Quality process (discussed later in this paper) a prototype concept design is assembled, tested, evaluated, and modified. The changes required to meet the customers' needs will then occur and are included in the very first production models to be manufactured.

To capture customer input, each of the participating states conducted focus group activities to quantify the basic technical requirements of the concept maintenance vehicle. The ideas that were generated by the focus groups were recorded in a format called an affinity diagram which is an organized output from a team brainstorming session or a focus group. The purpose of an affinity diagram is to generate, organize, and consolidate information concerning

a product, process, or complex issue or problem. Ideas were generated and written on a "post-it" which was put on the wall. After all ideas were generated by the group, the ideas were organized into logical categories and each category was named by the focus group itself. The focus groups used a relations diagram to study the relationships among aspects of the concept vehicle requirements and to identify root causes and effects. By identifying these relationships, the focus groups saw where to direct the resources of the organization when acquiring future vehicles. In general, all of the focus groups identified driver safety and snow plowing functions as high priorities.

Identification of roadway maintenance vehicle and equipment requirements was provided through focus groups consisting of DOT equipment operators, mechanics, equipment specification writers, maintenance managers, and maintenance supervisors. In addition, representatives from other professions who had an interest in the concept vehicle such as law enforcement personnel and emergency responders participated. These representatives are on the outer edges of the highway maintenance activities and, as a result, they provide some of the most innovative input to the process. It is a project objective to capture the vehicle requirements in “the voice of the customer” or in this case, in the "voice of the equipment operator." CTRE utilized the services of a private sector group facilitator during the focus group activities. The focus group sizes, to be most efficient, varied between 15 and 20 participants. Five focus groups were conducted at four different locations: Cedar Rapids, IA., Roseville, MN., St. Cloud, MN., and Troy, MI. The activities of the focus groups were documented to capture the entire list of ideas and functional descriptions for the concept vehicle. As a result of the employee focus group activities, each partner state's department of transportation has developed a prioritized list and a detailed description of the concept vehicle functions available for technology transfer applications.

More than 650 ideas were captured during the focus group sessions. The ideas were grouped into vehicle status categories (at rest, pre operations, roadway systems operations, and post operations along with administration and infrastructure) and then into technology categories. The following listing shows a sample of those ideas and how they are technologically grouped for further analysis.

- Communications:
  - Hands free communication
  - Real time link with garage for repair purposes
  - Communicate weather/road conditions to public
- Controls in the Cab
  - Voice activated controls
  - Heads up displays
  - Verbal read back of systems functions
- Durability
  - Vehicle/equipment that tolerates major impacts
  - Impact attenuator on rear of vehicle
  - Corrosion resistant components
- Environment Sensors
  - Roadway friction/surface temperature sensors
  - Chemical condition of roadway surface
  - Collision avoidance sensors when visibility is poor
- Maneuverability
  - Short turning radius
  - Low center of gravity
  - Articulated vehicle
- Operator Ergonomics
  - Reduced vibrations/noise in the vehicle cab
  - Air conditioning
  - Adjustable control panels to fit a wide size range of operators
- Payload
  - Larger payload
  - Carry multiple materials and change on the run
  - Measure on board payload
- Snow Plowing
  - Multilane clearing with one pass
  - Adjustable, automatic wing plow
  - Flexible plow to match roadway contours
  - Automated pressure on all plows
  - Vibrating plow
  - Teeth on scraper blade for grooving ice
  - Front plow and wing—eliminate the snow cloud
  - Plows capable of operating at normal traffic speeds
- Spreading Material
  - Eliminate lumps in material/detect spreader plugging
  - Application of material controlled by roadway condition
  - Precise placement of material
- Traction
  - All wheel drive
  - Anti lock braking system
  - Automatic inflate/deflate tires for improved traction
  - Hovercraft to eliminate the friction concerns
- Vehicle Avoidance and Sensing Systems
  - System to warn public when approaching vehicle from rear
  - Backing sensor/monitors
  - Vehicle/obstacle avoidance systems

- Driver Visibility
  - Rearward visibility of equipment
  - Visibility during white-out conditions
  - Windows that stay frost and ice free
  - Improve nighttime visibility
  - Scratch free windows
- Visibility of Vehicle to the Public
  - Highly visible, reflective color
  - Eliminate snow cloud
  - Plow lights higher than equipment operator's sight line
- Wheels and Rims
  - Non-cracking rims
  - On board jacks for wheel repair
  - Flat resistant tires

A workshop was held on April 23, 1996 in Detroit, Michigan. Attendees included representatives from state departments of transportation, system integrators, and manufacturers of vehicles, vehicle components, and on board vehicle communications. The workshop provided a basis for reviewing the project with potential private sector partners and soliciting their interest in joining the consortium.

Participants were divided into three breakout sessions: vehicle manufacturers, communications and technology providers, and equipment vendors. Each session evaluated the ideas generated by the focus groups and concluded nearly all the ideas could be met with current off-the-shelf technology.

Each session member was asked to discuss their experience or familiarity with public and private partnering. Only two private companies had partnering experience. A great deal of interest was expressed in pursuing public and private partnerships in the development of the concept vehicle. The research team will select firms most capable of prototyping a concept maintenance vehicle.

The results of the QFD activities, which are the functional requirements evaluation activities, will be documented using a "House of Quality" (HOQ) diagram or process. The HOQ diagram will record the technical requirements as defined by the focus groups. The technical requirements will be evaluated by the research team using a weighted factor analysis and will determine the relative importance of the requirements. The next recorded elements are the technologies available to meet the technical requirements and an evaluation to determine their feasibility. The HOQ process will determine if technologies are conflicting in their proposed applications. The last step will incorporate the feasibility of each technology requirement. This allows the research team the ability to make educated recommendations for the proposed technologies and their potential in this research project.

In cooperation with the private sector partners, the state partners will collaborate to predict the manufactureability and feasibility of systems and subsystems that have been defined by the focus groups. This activity will look at the development of a prototype vehicle (or possibly one for each participating state) and its evaluation. In addition, a fleet evaluation will be anticipated and 30 production vehicles are planned to be provided and distributed to the consortium states.

A cost effectiveness analysis from the DOT's viewpoint will be conducted. The objective of the cost effectiveness analysis is to determine the DOT's financial justification for purchasing the concept vehicle. The analysis will answer the question. "Will the concept vehicle pay for itself within a reasonable length of time?" Cost indicators will include considerations such as increased operator comfort, increased utility, increased safety to the driving public, reduced driver delay, improved communications, and increased productivity for both field and office personnel. It is the desire of the research team to utilize measurement indicators already in place in the consortium states maintenance management systems.

Phase II: Prototype Evaluation

During the second phase of this project, manufacturers, systems integrators, and the research team will develop one prototype concept vehicle (or possibly one for each consortium state). An evaluation plan will be developed. After the prototype vehicle(s) has been built, it will be tested and the necessary or desired modifications will be made to improve the vehicle's design. The vehicle's performance will be evaluated following the structured evaluation plan which will be developed by CTRE and approved by the consortium. A recommendation to proceed to Phase III or to stop at Phase II will be provided at this time. Task descriptions for Phase III, a budget, and a schedule will be prepared as part of Phase II recommendations.

Phase III: Comprehensive Vehicle Evaluation

In Phase III, several vehicles will be built for fleet testing. Although building several vehicles implies a significant expense, these vehicles are likely to be standard design maintenance trucks with advanced technology systems incorporated into them. Therefore, instead of purchasing vehicles only for a test, the vehicles will be available, after testing, for standard maintenance operations in the participating states. It is anticipated that 30 concept vehicles will be built and deployed for use, testing, and evaluation by the consortium state agencies. During Phase III, an

evaluation plan will be developed and a thorough evaluation of the vehicles will be made.

CONCLUSION

The project is ongoing at this time and is gaining momentum. The next step in Phase I is formation of public and private partnerships. That will be followed with a June meeting in Minnesota when the partners identify the customers requirements using Quality Function Deployment as a guide. Once the customer requirements have been defined, a prototype vehicle will be built and evaluated.

The schedule for completion of the entire project is driven by the desire to have a prototype vehicle(s) available for testing in winter snow removal operations during the winter of 1996-1997. To meet that schedule, the research team, which will include the private sector partners, the original consortium states, and additional consortium states who participate, will have to evaluate the technical requirements and assemble the prototype vehicle(s). At this time it appears that this is a justifiable schedule. After the prototype vehicle(s) has been in operation under normal winter snow and ice operations it will be evaluated for performance and modified as needed. The fleet evaluation of 30 new vehicles will need to coincide with the purchasing schedule for the participating DOTs. At this time it appears feasible to provide these production vehicles for the winter of 1997-1998. Many factors will influence this schedule, but the continued emphasis of the research team to keep the project on schedule will do much to accomplish this research project in a timely manner.

USING AUTOMATIC TRANSMISSIONS TO MEET YOUR NEEDS

Chris Collet
Allison Transmission, A Division of General Motors Corporation

ABSTRACT

This paper deals with the electronic enhancements available with the Allison MD and HD transmissions. It explains what combinations are recommended for utility and municipal vehicles. As a consequence, further explanation related to the work normally performed by body builders relevant to the features of the electronic transmission is covered. Additionally, the advantages of electronics for the mechanic when performing maintenance on the vehicle are discussed. These subjects include the use of the ProLink diagnostic tool, internal trouble codes, and maintenance tips. Other topics covered include transmission ratings, mechanical features, and specifying the proper transmission for the work you need to do. Summarizing all these features collectively provides the driver, mechanic and fleet manager an opportunity to achieve the greatest benefit and return on their investment.

SCOPE

This paper considers the evolution in technology within commercial truck transmissions. Therein exists the ability to take advantage of electronically controlled transmissions for increases in productivity and reduced societal costs.

INTRODUCTION

I ask each of you to pick a point in time (pick 100 years ago, 1000 years, 50 years, etc.). Once you pick your point in time, think about how man has always found ways to be more productive. Man is constantly looking for ways to improve a process whereby productivity increases and costs decrease. Today we are more productive than people 50 years ago. Fifty years ago, people were far more productive than their ancestors. Let us extrapolate this trend into the future. We can logically conclude that man will continue to find methods to further increase productivity at less cost to society. Technology will be exploited to increase productivity and reduce societal costs while improving our working environment.

EVOLVING TRANSMISSION TECHNOLOGY

Transmissions for medium and heavy duty trucks and buses have evolved significantly over time. The 1950's and 1960's saw automatic transmissions introduced into trucks and buses. The 1970's and 1980's saw both first and second generation electronic controls introduced. These controls displaced hydraulic valving while providing very precise shifting. Transmissions of these earlier eras were used for the sole function of transmitting torque to propel the vehicle.

Today, technology is emerging whereby powerful computers are being used to not only control the transmission's shifts but also control the operation of the vehicle. This technology is being pursued to increase the vehicle's productivity and make for a safer and more enjoyable work environment while providing a reduction in societal cost.

ELECTRONIC CONTROLLED TRANSMISSIONS

The latest generation of an electronically controlled transmission has recently occurred. Many individuals are not aware that these transmission systems can be used as a central controller for many vehicle functions besides transmitting torque. I will cover this technology and give examples of how it can provide the following:

- Control vehicle body functions;
- Provide system interlocks;
- Increase vehicle productivity ;
- Eliminate or reduce ancillary "add-on" systems;
- Make for safer operating environment;
- Make for an improved operator environment;
- Increase vehicle reliability and durability; and
- Simplify vehicle troubleshooting and repair

SYSTEM OVERVIEW

My expertise is with Allison Transmission. I will discuss the Allison World Transmission that was introduced in 1991. I have been involved with the World Transmission from its inception when the "Voice of the Customer" was being

developed. This was done prior to the actual design process to establish the needs of the customer.

The World Transmission is a heavy duty six speed, fully automatic transmission for medium and heavy duty trucks and buses. Its rating is up to 500 Horsepower. It uses "closed loop" technology to control shift quality. Central to its system is a digital microprocessor that monitors various input signals and makes appropriate commands. Besides controlling the shifting of the transmission, this controller can simultaneously be used as a central controller for the vehicle.

MAJOR COMPONENTS OF THE SYSTEM

The following components work together to make the system work:

- *Transmission.* The transmission is a six speed assembly. Its shifting is electronically controlled.
- *Electronic Control Unit* (ECU). This is the "controller" of the system. The ECU is a powerful 64K computer. The ECU is connected to the transmission and various components by using a wiring harness. The ECU not only controls the shifting of the transmission but also can control the operation of special functions beneficial for the vocation in which it is being used.
- *Shift Selector.* The operator of the vehicle makes range requests of the system through the shift selector.
- *Throttle Position Sensor.* This device senses the position of the accelerator pedal. When a vehicle has an electronic engine, this component is eliminated and the engine and transmission would talk electronically.
- *Vehicle Interface Module* (VIM). This is a pre-wired watertight box containing six relays. It serves as a convenient junction point for body builders. Commands from the ECU to the vehicle body are communicated through this relay box.
- *Vehicle Interface Wiring Connector* (VIW). This is a connector where the body inputs its request to the ECU. This connector exists for the convenience of the body builder.
- *Diagnostic Data Reader Connector* (DDR). This is a connector where a Pro-Link 9000 Diagnostic and Reprogramming Tool is connected.

FUNCTIONS

Previously mentioned was the ability of this system to control functions that enhance the operation and productivity of the vehicle. These will be referred to as Functions. A Function is defined as an operational instruction given to the ECU (or directed by the ECU)—resulting in the performance of a special transmission or vehicle response.

Three types of Functions exist. All utilize the ECU as the central controller: 1) *Input Functions* are activated and deactivated by switching electrical power or ground to the ECU; 2) *Output Functions* are used to activate vehicle systems or components when certain conditions are met; and 3) *Input/Output Functions* are a combination of Input and Output Functions

There are over 38 Functions that have been created thus far. These Functions have been developed considering the needs of each vocation for which the transmission is being applied. These Functions are developed to improve the vehicle's productivity, safety, reliability, serviceability and overall cost. An abbreviated list of the Functions includes: Secondary Shift Schedule, PTO Enable, Auxiliary Range Inhibit, Fire Truck Pump Mode, Automatic Neutral for PTO, Two Speed Axle Enable, ABS, Range Indicated, Output Speed Indicator, 4th Lockup Pump Mode, Automatic Neutral for Refuse & PTO Enable, and Automatic Neutral for Refuse Packer & PTO Enable with Service Brake Status.

EXAMPLES OF FUNCTIONS

Let us look at a few examples of the Functions with the World Transmission. I will start with a example to show you how simple it can be to integrate this system into a vehicle. Then we will look at more complex and highly productive systems.

Auxiliary Range Inhibit

Envision a vehicle where a device on the body is extended and your desire is that no one can accidentally shift the transmission into range while the device is extended. The device may be outriggers on a construction truck or the aerial bucket on a utility truck. This Function can be used to prevent accidental shifting into range by simply installing a proximity switch on the device to sense its extension. Each one of these Functions has an official circuit diagram. Each circuit has undergone Failure Modes and Effects Analysis (FMEA) prior to it being released and published.

Much of the wiring for this Function will already exist in the chassis. The Vehicle Interface Wiring Connector (VIW) will already exist. A technician would simply connect a piece of 18 gauge wire to Wire #155 at the Vehicle Interface Wiring Connector (VIW) and connect it to a simple single pole switch. The other side of the switch is wired to Wire #161 at the VIW. The Auxiliary Range

Inhibit Function is now fully wired. When the device on the vehicle's body is extended, the switch will be open. This interrupts the circuit path. Any attempt by someone to place the transmission in gear will be inhibited by the ECU. Only when the device is retracted and the switch is closed will the ECU honor a request for range. This is a very useful yet simple system to understand. Let us build on our knowledge and look at more involved systems.

PTO Enable

Think about a vehicle that uses a Power Take Off (PTO) as a secondary power source to operate pumps, generators, or air compressors. Your desire may be to control the operation of the PTO so it will only be engaged when conditions are appropriate. You may want to limit the engagement and operating speed of the PTO to prevent the overspeeding of the device the PTO is driving. You also may desire to restrict the operation of the PTO above certain vehicle speeds. These operating requirements can easily be achieved with the use of the PTO Enable Function. This Function is a combination of an Input and Output Function.

This system is only slightly more complicated than the previous example. This Function utilizes one of the pre-wired relays reserved in the Vehicle Interface Module. Let us look at the simplicity of this system. Wiring involves finding switched power in the vehicle and running it through a dash mounted toggle switch. From the switch, run a wire to both Wire #118 at the VIW Connector and the F2 Terminal at the VIM. Remember, the VIM is pre-wired. The F3 Terminal at the VIM is the output that is connected to the electrical solenoid of a "hot-shift" PTO. Now the ECU is controlling the operation of the PTO. Engagement and operational speeds are controlled by the ECU and can be field adjustable. The adjustment will be discussed later.

Consider the simplicity of the system and the benefits gained by using the transmission's ECU to control the PTO. The PTO is fully controlled by the ECU and no ancillary system had to be added to the vehicle. The installation is simple and well integrated. Simplicity will bring greater reliability. If any trouble-shooting is required in the future, the published diagrams should be universally known and apply to nearly all commercial trucks.

Automatic Neutral for Refuse Packer and PTO Enable with Service Brake Status

Productivity is of prime importance to refuse operators. Emerging in this industry are automated side loading trucks where a single person operates the entire collection process from the vehicle cab. No longer present are the one or two workers, at the rear of the truck, manually dumping refuse cans into the vehicle. The need of this industry is speed to collect refuse at minimal cost and risk to workers.

A Function has just been released for automated sided loading trucks. This Function interfaces heavily with the vehicle and body creating a highly productive process. The addition of this system on a truck can yield an increase in productivity of 100 extra refuse cans per day.

I will not go through all the details of the circuit but I will describe the full operation of this Function. When the operator stops for a refuse can, the operator begins to extend the arm of the body that will grab the refuse can. When the arm is extended, the ECU commands the transmission to Neutral Range. Second, the engine's fast idle system is enabled by the ECU. Third, the PTO is enabled by the ECU. Once the cycle is completed and the arm is fully retracted, the ECU will command the transmission to engage forward range provided the operator has the service brake pedal depressed. Also, the engine speed will be returned to idle.

ADJUSTABLE PARAMETERS

With the wide operational requirements of users and vocations, various ECU parameters (settings) are adjustable by the factory or in the field. Body builders who have acquired the training and equipment, find it easy to adjust the parameters in the ECU to suit the need of their body and customers. There are 22 parameters which are adjustable. Examples of parameters, often adjusted by body builders, are the engagement and operational speeds for the PTO. Parameters also exist for engagement and operation of the PTO based on transmission output speed (vehicle speed). The parameters are easily adjusted electronically within minutes. The adjustment is done using a very common diagnostic tool called Pro-Link 9000 with a special Reprogramming Cartridge. This tool connects to the vehicle's DDR Connector (typically under the vehicle's dash).

VOCATIONAL PACKAGES

The ECU can contain many Functions. Often a body builder will use several of the available Functions in the ECU to integrate the vehicle. Vocational Packages were designed to "package" many of the common Functions for a particular vocation. This enables users, dealers, and body builders to purchase trucks based on its vocational requirements and have the typical Functions for that vocation existing in the ECU. This means a truck intended

to be a fire truck needs to have its chassis "spec'd" and ordered with a Vocational Package that is useful for the fire truck body builder to use. A chassis that has an inappropriate Vocational Package in the ECU will have to undergo involved recalibration that can add delays and cost to the integration.

CHASSIS SPECIFICATIONS AND ORDERING

Two of the most important steps in the acquisition of a vehicle are the planning and communication prior to the chassis order being issued. I am speaking of the need for the user to begin the process by identifying the operational requirements of the vehicle. Then, jointly working with the truck dealer and the body builder, making sure the operational needs are well understood. This will help to assure the chassis arrives at the body builder in a useable configuration, negating the need for modifications and delays.

Allison is doing its part to help the communication process with truck dealers and body builders. Many truck dealer ordering programs are being supplemented with computer based systems that aid them with the specification process. By inputting vocational needs, the specification program will identify the proper ECU Vocational Package to order in the chassis.

CONCLUSION

Today, certain electronic controlled transmissions can be used as a controller for the vocational requirements of a vehicle. By utilizing them, an integrated installation can yield improvements in productivity, safety, convenience, and ease of maintenance with the overall reduction in societal cost.

DEPLOYMENT OF ROBOTIC DEVICES FOR HIGHWAY MAINTENANCE AND CONSTRUCTION

Thomas West
California Department of Transportation

ABSTRACT

The California Department of Transportation and the University of California, Davis have jointly established the Advanced Highway Maintenance and Construction Technology (AHMCT) Center to explore the application of automation and robotics in transportation infrastructure construction and maintenance. This paper presents a brief overview of current research being conducted by the AHMCT Center including descriptions and photographs of automated and/or robotic systems under development. Special emphasis will identify unique requirements imposed by the highway, the benefits of each system relative to conventional maintenance and construction operations, general system descriptions and the current status of six projects nearing final deployment in California.

INTRODUCTION

Of considerable concern to maintenance and construction engineers at the California Department of Transportation (Caltrans), is the ability to safely and efficiently perform tasks with minimal impact to the traveling public. This is a staggering problem as the increasing age of the facility dictates ever expanding levels of work. In California, this is exacerbated by recent reductions in the maintenance and construction work force coupled with rapid increases in traffic volumes and resulting congestion which continue to reduce the "window of opportunity" available to perform necessary operations. Even more challenging situations begin to surface as transportation engineers contemplate the implications of Intelligent Transportation Systems.

In response to these pressing concerns, Caltrans and the University of California, Davis (UCD) established the Advanced Highway Maintenance & Construction Technology (AHMCT) Center in 1989 to investigate the application of automation and robotics to highway maintenance and construction. The Center is jointly managed by Caltrans and UCD and base funding is provided by Caltrans, the Federal Highway Administration, UCD, and other public and private sources.

This paper presents a brief overview of current research being conducted by the AHMCT Center including automated and/or robotic systems currently being field tested or deployed in California. Special emphasis will identify unique requirements imposed by the highway, the benefits of each system relative to conventional maintenance and construction operations, general system descriptions and the current status of six projects nearing final deployment in California.

AHMCT CENTER EFFORTS

Transportation system maintenance and construction is essential to ensure the safe, efficient, and effective delivery of people, goods, services, and information. However, current transportation maintenance and construction activities depend comparably little upon high technology equipment or procedures relative to other industries. Many current activities are labor intensive and can expose workers and travelers to the risk of injury. The application of technological innovation and systems improvement can make highways safer for their stewards and travelers, speed task completion, and reduce associated costs.

Correspondingly, the goals of the AHMCT Center are to greatly improve the level of safety that now exists for maintenance and construction personnel, substantially increase the speed and efficiency of maintenance and construction operations, reduce the effect that maintenance and construction operations have on the traveling public, increase the reliability of the highway infrastructure, and mitigate environmental impacts of highway maintenance and construction activities.[1]

PROJECT DEVELOPMENT

Research and development projects undertaken at the AHMCT Center are selected for their potential to resolve significant challenges that affect safety, efficiency, and cost savings. A project begins with user surveys of perceived need and recommendations for service, process, method, or equipment improvement and innovation. Selected

projects must meet the test of broad application and demonstrate strong potential for successful field implementation as well as product commercialization.

The pre-prototype research phase involves thorough feasibility studies, cost/benefit analyses, and literature searches. Prototype development includes periodic design reviews and intensive evaluation by transportation maintenance and construction personnel. Observations from transportation workers are incorporated into prototype improvements until a field-operational engineering prototype is developed. This prototype is tested extensively in all environments and by actual users. Comments and recommendations contribute to continued improvements until a reliable prototype is developed. This "field prototype" is then deployed to various regions for long-term evaluations relative to operation, reliability, and its ability to satisfy the original project goals. Finally, product manufacturers advance the product from its prototype stage to commercial marketability so that it can become a useful and cost-effective innovation of benefit to all public and private transportation organizations.[2,3]

PRODUCT DEPLOYMENT

The following descriptions (AHMCT Center brochure, 1994) represent a small subset of products that the AHMCT Center is investigating and include prototypes in either the field testing or field deployment stage of development. These projects were selected to emphasize the wide diversity of maintenance and construction tasks addressed by the AHMCT Center as well as the associated multi-disciplinary teams necessary to provide successful technology solutions.

Longitudinal Crack Sealing Machine

Caltrans is responsible for maintaining over 15,000 highway miles of roadway. Repairing pavement cracks helps retain the structural integrity of the roadway and extends the time between major rehabilitation. Longitudinal crack sealing, an important subset of generalized crack sealing, can be a dangerous and tedious operation. The Longitudinal Crack Sealing Machine (LCSM) will enhance worker and traveler safety, lower highway maintenance costs, and improve efficiency in crack sealing operations.

The LCSM employs a self-contained modular design that simply mounts to any maintenance vehicle, thereby eliminating the need for dedicated vehicles for this activity. The driver of the vehicle is able to view the sealant applicator at work and simply follows the longitudinal crack. The applicator has been designed in two versions, one for crack sealing and one for crack filling. The crack sealing applicator maintains a reservoir of pressurized sealant thus forcing the material both into the cracks and into a flush overband configuration. Both applicators provide an adequate amount of sealant material regardless of crack width and depth. Figure 1 shows the sealant applicator in use on a standard Caltrans truck.

FIGURE 1 Longitudinal crack sealing machine.

Due to the significant increase in sealant speed, the LCSM has been limited by the commercially available sealant melters and the manner in which personnel re-stock sealant material to the melter. Accordingly, a new material handling approach has been developed which has included minimal additions to a standard sealant melter and has allowed the operation to proceed at an accelerated rate. Personnel requirements include a driver and one operator seated on the bed of the vehicle to provide blocks of sealant to the melter's material handling system.

A field prototype of the LCSM has been deployed with Caltrans maintenance personnel which has allowed debugging and minor modifications to best meet the needs of on-road operations.

Robotic System for Roadway Stenciling

Pavement markings are a necessary element of traffic delineation and control, but present significant safety problems during required installation and maintenance.

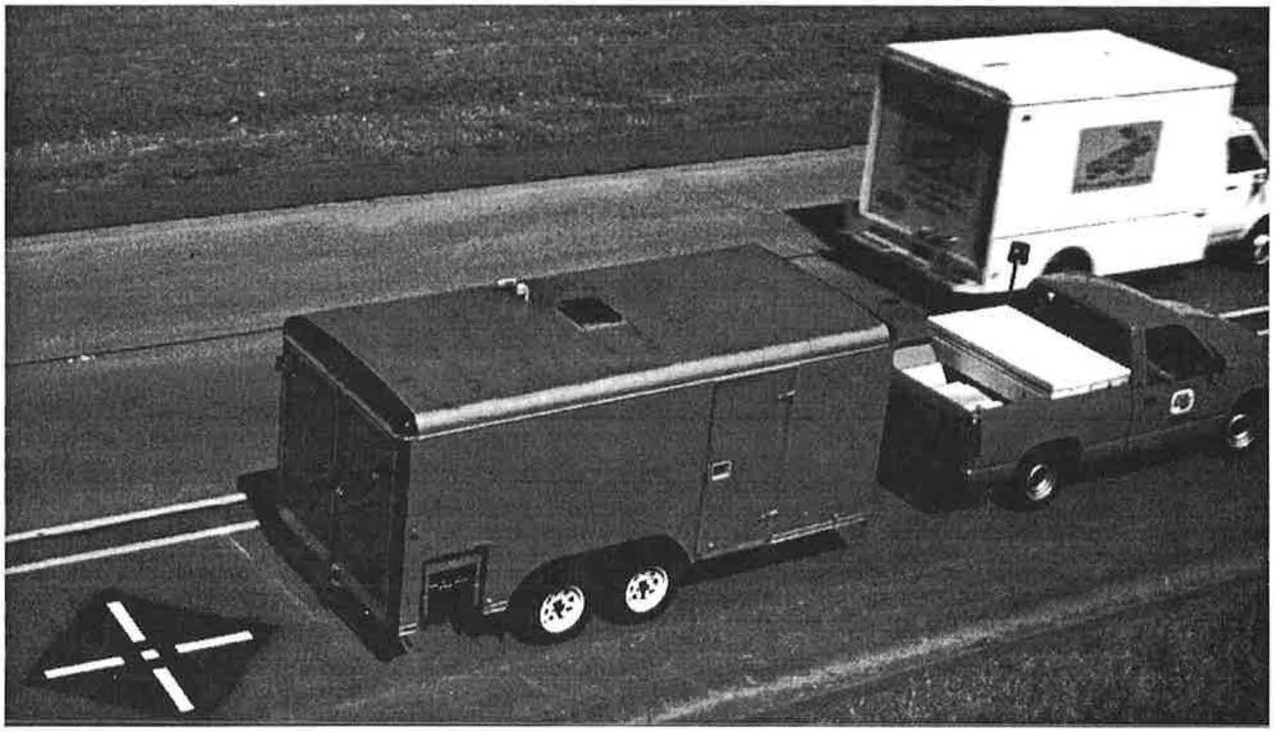

FIGURE 2 Robotic system for roadway stenciling.

Current methods to apply pavement symbols and signage require the manual placement of a stencil on the pavement, followed by the manual application of paint or the "torch-down" of a thermoplastic type material. Both procedures are very slow and labor-intensive operations that expose maintenance employees to traffic and possible injury.

An automated, robotic processing system has been developed that improves efficiency and worker safety using a spray gun that is guided by a robot manipulator. A single operator is now capable of planning the operation on-site, positioning the vehicle for proper alignment, and completing the stenciling operation from within the cab of the maintenance vehicle.

Developed in response to an employee fatality, the initial robotic sign stenciling machine focused on improving the safety of the application of photogrammetric "premarks" or targets. Premarks are currently painted by manual means on the road surface and are used in conjunction with aerial photography to calibrate vertical positions. A four-person survey crew may require five to seven days to paint target marks on 1.6 km (1 mi) of highway. The robotic stenciling system developed completes the same operation in less than one day.

The system consists of a self-contained gantry type robotic system housed inside a closed trailer. This is shown in figure 2. The gantry robot (x-y plotter) is designed to pass two rows of painting nozzles (one white, one black) over the asphalt surface to complete the mark. Motors and pneumatic cylinders are used to lift the stenciling apparatus from the truck to the ground, thereby eliminating the need for workers to be exposed to vehicular traffic on the roadway. All operation of the robot is completed from the cab of the vehicle, virtually eliminating traffic exposure.

The Robotic System for Roadway Stenciling has been successfully field tested throughout California and is currently being deployed on a state-wide basis.

Smart Herbicide Application

Vegetation control on the transportation system right-of-way is a necessary component of Caltrans' highway maintenance program. Uncontrolled weed growth impedes driver visibility, fuels grass and forest fires, and contributes to pavement degradation.

Caltrans employs an integrated system of vegetation control which includes mechanical methods, use of low-growing, drought tolerant and fire-resistant plants, and herbicides. Caltrans, committed to reducing the amount of herbicides used in vegetation control, intends to reduce its use of herbicides by 80% by the year 2012. The Smart Herbicide Applicator will help to achieve this commitment, reduce highway maintenance costs, and

FIGURE 3 Smart herbicide applicator.

improve working conditions for landscaping crews by intelligently applying herbicide accurately with minimal over-spray. This is achieved through the automated and targeted application of herbicide to plant material only.

The Smart Herbicide Applicator employs a vision sensing system to detect green plants and has a targeted field of view of up to 2.4 m (8 ft) perpendicular to the traveling vehicle. Image processing is used to identify the exact location of detected plants while the vehicle is in motion and leaf sizes as small as 0.125 m^2 (1.9 x 10^4 in^2) can be detected. A speed-compensated control system utilizes data from the image processor and a radar-based speed detector to activate the spray nozzles. The ground speed detector is necessary to determine the trajectory of the herbicide and the nozzle action required for targeting. The combination of this data enables the controller to specify the exact moment to actuate the appropriate applicator nozzle so that only the detected plant is targeted. Rapid-response spray nozzles on a boomless vertical nozzle bank precisely direct the application of herbicides to plant tissue and reduce over-spray. The Smart Herbicide Applicator is shown in Figure 3.

The field-testable unit, integrated on a standard Caltrans maintenance vehicle, is now undergoing testing and evaluation under regular maintenance conditions in Northern California. Regional vegetation control crews using the system are providing feedback for optimization of the system - a step critical to developing equipment acceptable and usable by the maintenance work force. A subsequent development project will modify the Smart Herbicide Application System for integration with the more modern chemical-injection equipment existing within the Caltrans vegetation control program.

Telerobotic Litter Bag/Debris Collection Vehicle

Litter bag and debris removal operations vary in procedure, but have in common low efficiency, moderate costs, and high risk of injury. Typical operations require a single worker to drive along the roadside, periodically stopping to throw bags or debris from the roadside into the cargo body of the truck. The Telerobotic Litter Bag/Debris Collection Vehicle, developed by the AHMCT Center, has demonstrated the potential to greatly improve safety and efficiency over manual retrieval. The objectives of this vehicle are to reduce the number of personnel required for the operation, keep the worker off of the unsafe roadside and away from the health hazards implicit in manually lifting litter bags and debris while still allowing efficient performance.

The Telerobotic Litter Bag/Debris Collection Vehicle has the multi-terrain ability to pick up litter bags and large debris from either side of the standard, but slightly modified, compacting garbage truck at levels within 1.2 m (4 ft) above or below grade. The hydraulic clamshell-type manipulator mounted between the cab and the compactor of a truck can grip objects such as single or multiple litter bags, tires, mufflers, and lumber. The maximum payload of the bucket is approximately 45.4 kg (100 lbs). Recent field testing has demonstrated that the machine has the ability to pick up several large tires or up to 8 litter bags at one time.

This design has the enormous benefit of automatically performing the repetitive task of bringing the load to the compactor, dumping the load, and returning the manipulator to a ready position, while allowing the operator to maintain his position within the cab of the vehicle. Macro and micro control of the manipulator is provided to the operator in a very user-friendly format. Macro control allows the complete pickup cycle to occur with the push of just two buttons and with a cycle time of under 60 seconds. More flexible or micro control is provided when debris or litter bags are placed in inconvenient locations as on the backside of guardrail or near roadway signs.

This machine has been successfully field tested throughout the state and is scheduled for statewide deployment in 1996.

FIGURE 4 Telerobotic litter bag/debris collection vehicle.

Teleoperated Front-End Loader

The use of heavy equipment, such as crawler tractors, dozers, and loaders, is crucial to highway maintenance and often used in hazardous operations. They are used to repair highway damage after an avalanche, clear landslides, clean up hazardous materials, and clear snow on winter storm-closed highways. In such operations - where soil and snow banks are unstable, road boundaries not recognizable, or toxicity of potentially hazardous spills unknown - operators work in a high-risk environment. Casualties and injuries occur every year across the nation, despite preventive efforts. Teleoperated machines have the potential to perform many of the required jobs and reduce worker exposure to dangerous conditions.

The Teleoperated Front-End Loader consists of a remote controlled system applied to a Case Model 621 front-end loader. The teleoperated concept allows for normal loader operation during conventional use. However, when repairing damage from unstable landslides or avalanches, an operator can pilot the equipment safely from a distant or remote location.

The teleoperation system consists of an on-loader computer-based control system, an operating control computer, a remote operating unit, a full-duplex spread spectrum radio frequency communication link and actuator interfaces. Two remote operating units have been developed; a stationary on-truck workstation and a backpack style portable unit. Figure 5 shows teleoperated control with the backpack style portable control unit. The teleoperation system is capable of controlling the front-end loader with all operations including vehicle mobile controls and bucket motion controls. Several semi-automatic functions such as return to dig and travel height were implemented to speed up operations. The system has built-in safety features including reliable communication, emergency stop and automatic failure stop. The Teleoperated Front-End Loader also has been integrated with a three dimensional color video/audio feedback system. The video/audio feedback system enables the operator to regain the major senses, as to the status of the vehicle and position of the vehicle relative to the points of operation, which are lost during remote operation from a distance greater than 61 m (200 ft).

Tests and evaluations have been conducted at various sites within California, and the overall performance of the Teleoperated Front-End Loader has been very satisfactory according to user surveys. Productivity improvements also have been shown. Statewide deployment of this and two additional units will be complete by late 1997.

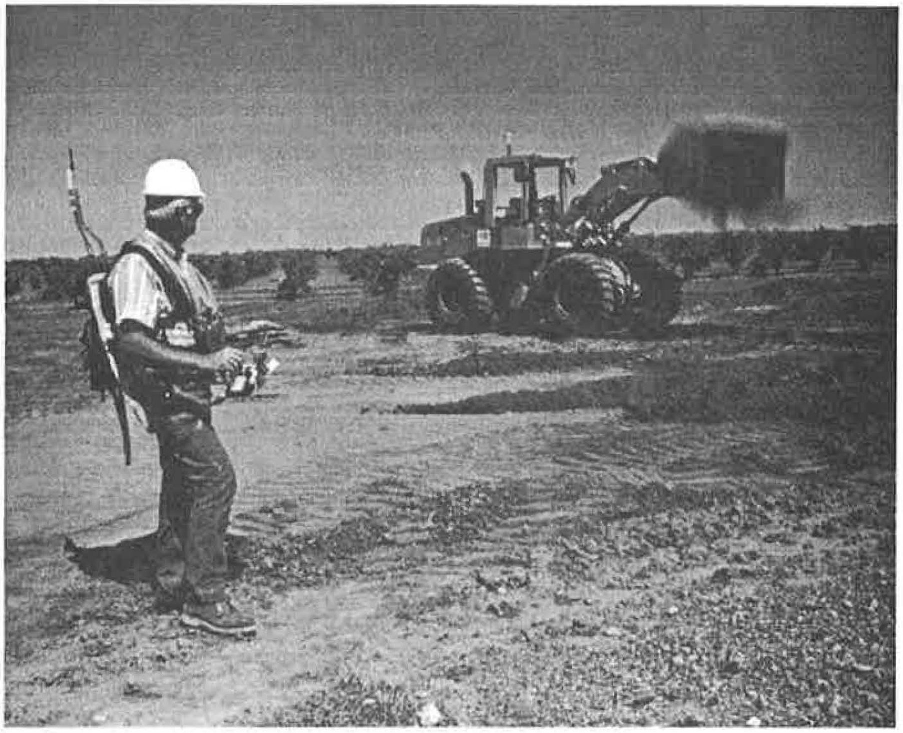

FIGURE 5 Teleoperated front-end loader.

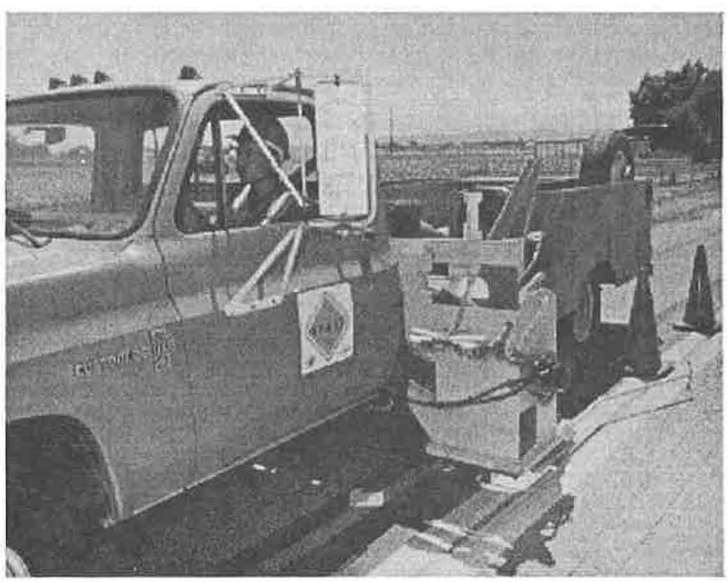

FIGURE 6 Automated machine for cone placement and retrieval.

Automated Machine for Cone Placement and Retrieval

Most highway maintenance and construction operations require a means of separating the work zone from lanes of traffic and traffic cones are one of the most common items used to delineate these work areas. Cones are one of the most readily used markers since they store in a very compact form and require no assembly prior to placement. Deployment of the cones is presently achieved by a person riding on the exterior of a modified vehicle. This person is typically either standing in a basket at the end of a truck or sitting near ground level between the axles of the customized cone body truck. Although the traffic cone is one of the most efficient methods of temporarily delineating areas of roadway, a considerable amount of manual effort is required and personnel are exposed to the hazards of traffic in addition to the physical exertion involved in handling the cones.

The AHMCT Center is developing a machine that will mechanically place and retrieve cones thus reducing worker exposure to these hazards. The automated cone machine will be incorporated onto the existing cone body, thus allowing the existing Caltrans fleet to be retrofitted with this automated equipment. Cones will be placed in the forward travel direction at speeds as high as 32 kph (20 mph). Cone retrieval will be performed in either the forward or reverse directions, at the operator's discretion, at speeds as high as 16 kph (10 mph). The machine is designed so that no on-site set up is required; deployment and stowage will be simple and fast. Furthermore, the driver's operational requirements are similar to the current approach. Under normal operation, the operator will be in the truck cab, but manual operation, as currently performed, will still be possible in the event of unusual circumstances. This application of automation significantly increases operator safety while retaining all the capabilities of the present operation. Figure 6 shows initial prototype testing.

Final field testing of the Automated Cone Placement and Retrieval Machine is slated for 1997.

SUMMARY

While considerable research has been conducted on automation and robotics for the building industry, primarily by Japanese companies, comparably little work has occurred worldwide on the application of automation and robotics to transportation maintenance and construction.[4] This paper has attempted to present a brief description of the AHMCT Center, an international leader in the application of technology to transportation maintenance and construction. The six projects described in the proceeding pages present only a subset of work conducted by the AHMCT Center and further information can be obtained by contacting the author.

ACKNOWLEDGMENT

The author gratefully acknowledges the California Department of Transportation and the Federal Highway Administration for their generous support of the Advanced Highway Maintenance & Construction Technology Center.

REFERENCES

1. Ravani, B. and West, T. (1991), "Applications of Robotics and Automation in Highway Maintenance Operations," *ASCE 2nd Annual International Conference on Applications of Advanced Technologies in Transportation Engineering*, pp. 61-65.

2. West, T., Velinsky, S., Ravani, B. (1995), "Advanced Highway Maintenance and Construction Technology Applications - Towards the Future Generation of Highway Machinery," TR News, January-February 1995, Number 176, pp. 17-23.

3. Ravani, B., Velinsky, S.A., and West, T.H. (1993), "Requirements for Applications of Robotics and Automation in Highway Maintenance and Construction Tasks," *Proceedings of SPACE '94 - ASCE Conference on Robotics for Challenging Environment*, pp. 356-364.

4. Zhou, T. and West, T. (1991), "Assessment of the State-of-the-Art of Robotics Applications in Highway Construction and Maintenance," ASCE 2nd Annual International Conference on Applications of Advanced Technologies in Transportation Engineering.

EQUIPMENT MANAGEMENT SYSTEM

Glenn Davison, Charles H. Goodspeed and David Fluharty
University of New Hampshire

ABSTRACT

State and local municipality infrastructures include buildings, highways, and water and sewerage treatment plants. Public Works Departments (PWDs) operate and maintain these public facilities using a diversity of maintenance equipment, supplies, parts and fuels. PWD management structures evolve or are established to perform day-to-day tasks and handle their financial needs. Management structures vary according to department size, however, common to all PWDs is acknowledged personnel responsibilities that fall into three categories: a) administrative, b) management, and c) staff. An equipment management system to serve the responsibility needs of these three employee categories requires four modules: a) equipment inventory, b) maintenance and scheduling, c) parts and supplies management, and d) financial analysis options. Maintenance Equipment Management System (MEMS) is a software package sufficiently generic to meet the diversity in PWD management needs. This paper examines the interaction of PWD employees and illustrates management program tools and associated data files to serve PWD staff needs. Guidelines are given that identify training, organizational and hardware needs to successfully implement an equipment management system.

INTRODUCTION

State and Municipal Public Works Departments (PWDs) maintain their regional infrastructure, maintenance of other agency's or department's equipment, and operate public services. Public infrastructure maintenance responsibilities include highways, water and wastewater treatment facilities, cemeteries, building and grounds, and recreational facilities. Many PWDs maintain vehicular equipment for fire, police, ambulance, and school departments as well as administrator vehicles. Management and operation of treatment plants, solid waste facilities and construction capabilities are typical responsibilities of public works departments. PWDs vary in size from large state highway agencies to small municipalities. New Hampshire Department of Transportation (NHDOT) is a relatively small state DOT and has more than 2000 pieces of equipment. Durham, New Hampshire is a small municipality and has 100 pieces of equipment. The NHDOT equipment budget is approximately $8,510,000 of which $2.8 million is spent on parts and supplies, $3.4 million on fuels and $500,000 is spent on equipment replacement. Durham on the other hand has an equipment budget of $194,200 of which approximately $78,000 is spent on parts and supplies, $24,000 on fuels and $43,000 on equipment replacement. An equipment inventory component must have the flexibility to handle in excess of 10,000 pieces of equipment with the same effectiveness as an inventory with less than 100 pieces. Maintenance Equipment Management System (MEMS) uses DBASE, compatible with most database products on the market, a database which does not limit the number of entries in the inventory.

Managing the various types of government owned equipment at the local and state levels requires equipment management characteristics unique to PWDs. Unlike fleet operators that manage semi-tractor trailers, cabs, buses, or leased passenger vehicles, PWD equipment managers are responsible for continuously running plant machines, construction equipment vehicles, and a variety of hand tools. This diversity of equipment type, age, fuel usage, and operators necessitates flexibility in a management system to handle these variations in documenting for this variety of equipment and associated parts and supplies.

State and local employees with public works responsibilities typically involves three employee categories: administrator, management, and staff. Large PWD management structures have positions in each category where small departments may share in accordance with local needs responsibilities with other departments or with elected municipal officials. Regardless of department size, budgets must be prepared, moneys allocated and PWDs managed. PWD administrators to prepare and defend budgets need department expenditure reports, planning reports and staffing needs. Management is accountable for accumulating these reports and staff is typically delegated to record the information as tasks are performed. Staff typically records their activities through work orders, purchase orders, work completed reports, and parts and supplies used. This description of PWD management structure illustrates the interaction of

responsibilities and data transfer. The MEMS program is written to be WINDOWS 95 compatible to minimize the program learning curve. The program allows users to tailor menus and data files to meet their departmental needs and to minimize department restructuring to implement a program management system.

Department personnel contemplating the implementation of a management program must have administration, management and staff support; sufficient hardware for all program users; training time and flexibility to reorganize inventories and possible staff responsibilities. Committees reviewing possible equipment management programs should select a program requiring a minimum of departmental restructuring to minimize the learning curve and maximize the potential for implementation success.

EQUIPMENT MANAGEMENT SYSTEM COMPONENTS

There are four primary components to any equipment management program applicable for PWD use: 1) equipment inventory, 2) scheduling and maintenance, 3) parts and supplies, and 4) financial analysis options. A MEMS screen enables a user to access each of the components. Using WINDOWS 95 standards provides users with a familiar well documented interface. Data files within each MEMS component are defined to be compatible with typical PWD needs. Three data files are defined for the municipal equipment inventory component: a) equipment information, b) preventive maintenance schedules, and c) employee and departmental records. The scheduling and maintenance component has two files: a) scheduled maintenance and b) completed work. There are four data files for the parts and supplies component: a) inventory, b) purchasing, c) consumption, and d) approved vendor list. The financial analysis component completes financial studies using user specified boolean and program data file variables. Default studies are included in the program.

EQUIPMENT INVENTORY

The three categories of municipal employees responsible for PWD activities need access to equipment inventory information. MEMS screens give users direct access to their desired information. Inventory files are cross linked and accessible by all MEMS components to facilitate access to inventory information for preparing work orders, purchase orders, and financial studies. Administrators can access inventory information to review planning and budget information through the financial analysis component.

Administrators and managers can use the same menus to evaluate options to contract all public works services; to buy, lease or rent equipment; to contract for purchasing supplies; and to prepare information to float bonds to upgrade selected municipal infrastructures. Managers can access equipment inventory to determine availability when scheduling resources for construction and maintenance projects. MEMS enables administrators and managers to access inventory information needs through browse, search, and sort options. Staff, including secretary and maintenance personnel, are able to transparently access inventory information while preparing work orders, purchase orders and scheduling preventive maintenance.

Inventory information is stored in a file containing 38 fields. A second file stores preventative maintenance tasks, schedules indicators, and a description of the maintenance (see Table 1). Variables used in MEMS are stored in either character, numeric, or date formats as shown in Table 1a. Preventive maintenance is segregated by summer and winter season to account for variation in equipment usage. For example, summer usage of a dump truck may consist of hauling leaves, loam, or solid waste which is light compared to winter plowing when the truck is fully loaded with sand or salt and pushing snow. Gas consumption in the summer under light use may be as high as 10 miles per gallon compared to a few miles per gallon under heavy winter use. Dump truck preventive maintenance typically requires different preventive mileage indicates during summer use versus winter to account for these variation in miles per gallon. An additional inventory file stores typical equipment operator and department ownership information.

MAINTENANCE SCHEDULING

Scheduling information can be used by administrators to evaluate staff work loads, maintenance capabilities and job descriptions. Managers use scheduling information to financially evaluate in-house maintenance capabilities versus contract alternatives. Many public works managers find it more economical to contract for specialty maintenance because of the specialized equipment and job training cost; for example, heavy truck transmission overhauls.

Scheduling maintenance addresses various issues including safety items, preventative maintenance, warranty stipulations, and repair work. Scheduling warranty inspections and preventative maintenance saves money by validating warranties and reducing the number of

TABLE 1A EQUIPMENT INVENTORY VARIABLES

Character	Numeric and Dates
Equipment ID	Mileage at Purchase
Size	Inspection Month
Serial Number	Model Year
Model Number	Purchase Date
VIN Number	Purchase Price
Department	Present Value
Description	In Service Date
License Plate Number	Mfr. Warranty Exp. Date
Manufacturer	Extended Warranty Exp. Date
Sales Vendor	Trans. Warranty Exp. Date
Gross Vehicle Weight	Other Warranty Exp. Date
Purchase Order No.	
Operator ID	
Mfr. Warranty	
Extend Warranty	
Trans. Warranty	
Other Warranties	
Fuel Type	
Comments	

TABLE 1B MAINTENANCE SCHEDULE INDICATORS

Maintenance Task
Summer Indicator (miles), (weeks), (hours), (fuel consumption)
Winter Indicator (miles), (weeks), (hour), (fuel consumption)
Memo Describing Preventative Maintenance Schedule

breakdowns that cause work stoppage. MEMS scheduling screens enable a user to access all tasks associated with scheduling including preparing work orders, purchase orders, and completed work reports.

Two files are used in MEMS to priority schedule and record maintenance activities. The schedule file stores the work orders (see Table 2a) to be performed, parts and supplies needed and staff assigned to the project. The maintenance history stores completed work order information (see Table 2b).

Equipment maintenance can be scheduled using four priorities: 1) safety, 2) preventative, 3) repair, and 4) other. Safety maintenance addresses repairs that contribute to operating safety, such as replacing stop or signal lights. Preventative maintenance includes routine maintenance affecting operating performance, for example oil changes, tune-ups and tire replacement. Repair maintenance is maintenance required when a failure occurs. Annual inspections, seasonal changeovers, and warranty and guarantee work fall into the other category. Safety maintenance always takes the highest priority. The priorities assigned to the remaining three categories are at the manager's discretion as it depends on current status of equipment and staff.

MANAGEMENT OF PARTS AND SUPPLIES

Many managers are attempting to stock only frequently used parts and supplies, those needed for emergencies, or those typically needed at off hours when local suppliers are not open. These cost savings approaches to managing parts and supplies requires continuous evaluation of a department's parts and supplies consumption patterns. Managers and staff needs dictate when stocked parts or supplies become low, when they are no longer used, or when a particular part or supply consistently prematurely fails or induces failures. Staff needs easy access to parts and supply inventories to prepare work orders and purchase orders, schedule and record equipment maintenance, and store and retrieve parts.

TABLE 2A WORK ORDER VARIABLES

Equipment ID
Maintenance (coded tasks)
Priority
Trigger
Assigned Mechanic
Date maintenance due

TABLE 2B MAINTENANCE HISTORY VARIABLES

Work Order Number
Reference Number
Authorized Maintenance
Maintenance Keys
Maintenance categories
Mechanics
Equipment ID
Owner Department
Labor in hours
Labor cost
P.M. Trigger

MEMS allows users to identify parts by name, number, vendor, bin/shelf location, upper & lower order limits, prepare purchase orders, and monitor consumption (see Figure 3a). Order limits are included to define the minimum recommended stocked quantity to place an order and a maximum number of items that should be ordered. Associated with the vendor list are keywords identifying the parts and supplies the vendor sells, as well as respective unit costs. Miscellaneous work orders can be used to account for supplies not directly related to a single maintenance work order; for example, windshield washer fluid, spray paint, and other cleaning and lubricant fluids. MEMS upgrades inventory files as parts and supplies are purchased and consumed through purchase orders and work orders respectively (see Table 3b and c).

Part and supply inventories provide a quick reference to part numbers, part names, vendors, stock locations, and order limits. These files organize ordering by accounting for delivery time, special orders, and bulk purchases which reduces the potential to overstock or deplete stock.

FINANCIAL ANALYSIS

Cost conscious PWD staff perform various financial analysis studies to competitively evaluate alternatives.

TABLE 3A PURCHASE ORDER VARIABLES

Character	Numeric
Part description	Quantity
Purchase Unit	Unit Cost
Purchase Order	
Vendor	
P.O. Status	

TABLE 3B PARTS AND SUPPLIES INVENTORY VARIABLES

Part No.
Stock Location
Inventory Description
Purchase Unit
Vendors
Barcode
Maximum reorder
Reorder Indicator

TABLE 3C WORK ORDER VARIABLES

Work Order No.
Equipment ID
Maintenance Cat.
Part No.
Quantity Used
Unit Cost
Stock No.
W. O. Date

MEMS enables users through boolean specifications to perform comparisons on the information stored in the program files. Common financial evaluations are programmed in MEMS to facilitate quick studies. Examples of available financial study tools are listed in Table 4.

- *Equipment Replacement*: Replacement of high cost items is a difficult budget line item to defend. Studies to defend replacements include life cycle cost analysis, diagnostic and testing of equipment and fluids; and unit maintenance cost analysis on repair versus replace, rent versus lease or contract. Data for these studies is taken from the inventory and work completed files. When the analysis shows replacement, further studies also may be prudent evaluate upgrading to meet future needs.

TABLE 4 FINANCIAL ANALYSIS OPTIONS

Equipment Inventory	Maintenance Life Maintenance Cost vs. Added Life Keep/Rebuild/Trade Equipment Use vs. Need Upgrade/Downgrade/Same Diagnostics Fuel & Oil Consumption Repeated Failures Oil Analysis Contracted service vs. In-house Cost, Down time, Labor Maintenance agreements Purchase/Renew/Discontinue Labor Availability Time
Maintenance Scheduling	Work Load vs. Staff Positions Work Categories vs. Staff Skills
Parts/Supplies	Maintenance Performance Name Brand vs. Generic Heavy Duty vs. Light Duty Stock vs. Purchase As Needed Consumption Rate Availability (24 hour) Order Limits: Minimum & Maximum Consumption Rates Availability Bulk Purchasing Vendor Service Parts/Supplies Availability Competitive Pricing Fuels On Site Storage vs. Off Site Service

- *Contract Services*: To evaluate the alternative to contract for services, an analysis can consider availability of staff and equipment by using data in the inventory file and maintenance schedule files. A time and cost analysis can be performed using the data in the completed work order file containing labor time, parts and supplies consumed, and downtime. Downtime analysis can be investigated using the parts and equipment files to determine potential delay times.
- *Diagnostic Analysis*: Scheduling and completed work order files can be used to identify changes in fluid consumption and repair frequency. A diagnostics analysis is an alternative for identifying potential problems or the cause of an existing problem. MEMS can perform diagnostic analysis based on changes in fuel and oil consumption, repeated failures on a particular vehicle, or vehicle class.
- *Productivity Analysis*: An analysis using maintenance scheduling files can evaluate staff productivity by comparing frequently performed tasks. Evaluation of work load versus staff positions identifies the need to expand or reduce staff. Options to address time difficulties are: priority scheduling, use of contracted services, or additional staff. Evaluation of work categories versus staff skill may help determine the need for contracted services, training, and new positions.
- *Maintenance Performance*: A performance analysis uses completed maintenance work information to compare one brand with another. Thus, analysis can identify repeated failures on new or replacement parts. Identifying predictable failures can save money by replacing the part before failure or reporting the failure to the manufacture for replacement assistance (NHDOT found a predictable part failure on a vehicle model that the

TABLE 5 POTENTIAL SAVINGS ALTERNATIVES ILLUSTRATED BY MEMS COMPONENTS

Equipment Inventory	Reduce Operating Costs Extend Life Span Extend Reliability Reduce Down Time
Maintenance Scheduling	Increase Productivity Best Use of Staff Time Best Use of Staff Skills
Parts/Supplies	Increase Inventory Accountability Increase Parts/Supply Quality Reduce Over Stocking & Shortages Special Purchases Sales
Analysis	Increase Analysis Capabilities Increase Analysis Speed Increase Report Generation Speed Increase Data Integrity

manufacturer replaced at no cost). A similar analysis can be used to evaluate maintenance performance when the vehicle is subjected to heavy and light duty.

- *Parts and Supplies Analysis*: Performing analysis on stocked parts versus purchasing parts as needed may determine alternatives to reduce costs. Over stocking ties up funds and can lead to outdated stock; however stock depletion can cause unnecessary down time. For example, parts and supplies associated with snow removal equipment, hydraulic hoses and fluid, may not have an high annual consumption rate but may be in high demand during winter months. Availability analysis is performed to identify parts that are not readily available. There are three considerations that should be evaluated when determining ordering limits: consumption rate, availability, and bulk or special purchasing. Items that are not readily available may need higher minimum ordering limits to allow for delivery time.
- *Vendor Services Analysis*: A vendor service analysis can be performed for part and supply vendors to evaluate competitive pricing. This analysis cross references vendor lists in the purchase order file, to evaluate delivery time, availability of items (back orders), and pricing.
- *Fuel analysis*: Fuel consumption analysis is a good tool to evaluate on site storage versus contracted services. Evaluating fuel and maintenance costs versus contracted services can help determine the best alternative for a PWD.

IMPLEMENTATION AND POTENTIAL SAVINGS

To achieve maximum benefit implementing an equipment management system requires the full support of all employees participating in a PWD. Implementation requires the acquisition of sufficient and appropriate equipment to operate a management program; this can include computers for administrators, managers, and secretaries as well as computers or data input devices in maintenance shops and adjacent to bulk fuel dispensation equipment. Many times stockrooms may need organizing for compatibility with bin, shelf and location codes. Every new program has unique characteristics that, when understood, enable the user to attain maximum utilization of the program capabilities; training is primary need for all staff directly involved in the use of the program

PWDs using an equipment management program have the potential to save money through better inventory management, effectively scheduling maintenance, purchasing parts and supplies at competitive prices, and evaluating other operating alternatives (see Table 5).

SUMMARY

- The components to the MEMs program are: a) equipment inventory, b) scheduling maintenance, c) parts and supplies inventory, and d) financial analysis options.
- A successful implementation of an equipment maintenance program requires the full commitment of the PWD employees, financial support sufficient to cover hardware set-up costs and training.
- PWDs using an equipment management program can attribute significant maintenance savings through financial analysis options programs such as MEMS offers a user.

VERMONT'S "OFF-THE-SHELF" EQUIPMENT MANAGEMENT SYSTEM

George Combes
Vermont Agency of Transportation

BACKGROUND

In the late 1970's the Vermont Agency of Transportation (VAOT) decided to build a computerized equipment management system. A number of staff personnel attended the "Equipment Management System Training Course" offered by the Federal Highway Administration. The course material served as the base reference document from which the system would be developed. The system was to provide decision-making information not readily available in the existing manual system as well as automate the accounting system under which the internal service fund operated.

Inventory management was first addressed with a purchased inventory system installed on the mainframe. From this, work was initiated both on a repair order system and the accounting system as well as a number of changes to the purchased inventory software, some of which were major. The garage operation was low on the totem pole for system analyst and programmer time so the project went very slowly.

In the mid 1980's, portable computers (PCs) arrived making it possible to automate some of the functions at the Garage using Garage staff to do the programming. This helped in a number of areas but also added to the problem in the mainframe development of maintaining and updating multiple files and records. Basically there was very little interfacing within the systems without a lot of manual intervention.

By the late 1980's, the mainframe programming work was getting to be very costly and slow because the new work was impacting on the earlier programs. The programmers that had done the earlier work had moved to new positions and very few people were left that knew anything about the system. Essentially at this point emphasis was shifted to fix and maintain the mainframe and not add anything new.

We started to investigate what was available for software for equipment management systems through the private sector as well as looking at what some of the other states had. The decision had been made that no more would be spent to try to finish our system. Around 1990, I was informed that the Agency had awarded a contract for a new agency accounting system and that it had a fleet management system in it. It did have accounting elements but our partial equipment management system actually was better than what was to be provided in the new accounting system. Based on what we already knew was available from the private sector and the costs of these systems it was decided not to modify the new accounting system. In 1992, we were given the green light to develop a Request for Proposals (RFP) for an equipment management system.

COMMERCIAL SYSTEMS

In the early 1990's, we found that there were 25-30 different equipment management systems on the market. These ranged from small PC systems with limited capabilities to large mainframe systems with almost unlimited capabilities. There were a variety of programming languages and you could find one for almost any operating system. The price range was from less than $25,000 to about $500,000. All less than what we had spent trying to develop a system in house.

All of them contained some type of inventory management system and a repair order system with preventive maintenance scheduling. The comprehensive systems provided capabilities to track and compare makes, model, and year of vehicles against each other; identify recurring repair problems; perform replacement analysis; oil analysis; motor pool dispatch; warranty claims submittal and management; tire management; fuel management: accident reporting and more. Almost any feature you could want you could find a system which had it.

It was difficult to find a user that was not happy with the system that they had purchased. Some wished they had purchased one or two of the optional features available for the system they had, but had no regrets that they purchased the system. One interesting thing we found was that very few users use the total system they purchased. Most purchased the system to eliminate a particular problem and that's how they used it. Each system has its strong points and that was what the user was interested in when they purchased the system. Every system also had some weak points. Replacement analysis seems to be a common one. Although every user indicated that they were pleased with the support the

vendor provided after installation, it was clear that not everyone took advantage of their services or felt they could have been better. Others clearly had an outstanding working relationship with their software vendor.

REQUEST FOR PROPOSAL

A six-member committee was set up to develop a RFP for the purchase of Equipment Management System software and to evaluate the proposals. The committee consisted of:

- Maintenance Engineer (Supervisor of the Districts);
- Garage Superintendent (Statewide Fleet Manager);
- Shop Maintenance Chief (Statewide Equipment Maintenance);
- Storekeeper (First Line User);
- Systems Analyst (Computer Systems); and
- Chief of Financial Services (Accounting).

The intent was to provide a cross section of users and affected parties. This was to ensure that all the needs were met and the desires addressed. The committee worked with literature that had been collected on commercial systems; the RFP developed by the State of Maine for a Fleet Management System; and the good and bad points of our current system. From that a list of "must have" items and features was developed along with a list of "would like" items. This resulted in a thirteen-page list of items included as part of the RFP on which the bidders were required to respond: a) currently in system; b) will be included; or c) can not be provided.

Some of the key features we wanted are:

- On line data entry and update. We were after real time information.
- The ability to combine units yet track their maintenance histories and costs separately. For example an aerial lift truck would be made up of the truck chassis and the aerial lift unit.
- Multiple closing of repair orders. Initial closing when work was completed and final closing when the work and parts used were approved.
- Trouble tickets and warranty alerts appear on the screen when the repair order is opened.
- Use the American Trucking Association's (ATA's) system, reason and work accomplished codes. We did not want to develop our own coding structure and ATA has the most complete system we are aware of. Plus it would be a system common to most other users.
- Automatic preventive maintenance scheduling with the ability to select by unit schedules based on: fixed dates, usage, or fuel consumption.
- Both labor and parts to use bar coding for data entry. Wanted to reduce or eliminate the manual data entry.
- So called paperless shop. With the bar code data entry and "real time on-line update" it is possible to have the paperless shop. However in actual practice you will find that a lot of paper will still be generated. Auditors still want hard copy documentation and the technicians want written instructions.
- Automatic reorder of parts based on usage and the ability to adjust to seasonal demands.
- The ability to take partial physical inventories. We do not want to shut the shop down to take complete inventories.
- The ability to track indirect costs and ensure they are covered in the shop flat labor rate.
- A tool control system to control issues and returns to the tool room, depreciate capitalized tools, and provide a maintenance and cost history.
- An accident reporting system to track type of accidents, costs, and the operators involved.
- A replacement analysis system based on maintenance histories, projected costs and usage.
- A warranty claims submittal system to retrieve data from the repair order system, to support and track warranty claims, and credit the units on receipt.
- Multiple security levels with an audit trail to document who did what.
- An "Ad Hoc" report writer system for preparing custom reports.
- A whole list of interfaces to and from the Agency accounting system.

The RFP was sent to 10-12 companies of which four responded. The committee quickly discarded two of the proposals, as they fell short in too many areas. The other two could provide almost everything we wanted and their ratings, done individually by the committee members, were very close. Both were brought in to do presentations and answer questions. These sessions were video taped. The presenters were told that they were being taped and any promises made during the presentation would be included in the contract if they were the successful vendor. The tapes also were intended for referral by the committee during the selection process.

In the first round of evaluations, prior to the presentations, the system finally selected was rated number two. After the presentations it was the unanimous choice. In late June 1993 the contract was issued with a November

1 implementation date to bring the Central Garage location on line.

IMPLEMENTATION

The primary implementation team consisted of the Shop Chief, Field Maintenance Supervisor, Office Manager, and Garage Superintendent. We had to learn the system and develop a good understanding of it before we could start the implementation. Training sessions were scheduled along with bringing in a programmer for the interfaces and utility programs to convert our existing files. We found out very quickly the reason this commercial software, and I suspect most others, works so well for such a wide range of users is the built in flexibility in how you operate the system. You have a lot of options. The training was done in three to five day sessions starting with an overview followed by the control module and then the operating modules.

The biggest problem we faced was the temptation to modify the system to make everything the same as we were used to. Some differences were just in terminology such as repair order instead of work order. Others meant a small change in our procedures or that we didn't know how to make the system do what we wanted. The only changes we did make were for the interfaces. Most of the other changes we thought we needed were resolved by the vendor showing us how to make the system do what we wanted. The reason we resisted modifying the system is that the State commonly buys software and modifies it at high cost then has problems making it work. In the end, we made the right choice. The system works very well and the changes we had to make to our procedures to use it had no negative impacts and in some cases turned out as an improvement.

The Central Garage location did go on line November 1st as scheduled with the 13 field locations brought on line by May 1994. The vendor trained the Central Garage personnel and trained the trainers who trained the field personnel and brought those sites on line.

ON GOING SUPPORT

One advantage to a commercial system is the dedicated on going support after installation. This will vary from vendor to vendor and should be a key item in the evaluation and selection process. Some items to look for in continuing support are:

- *Troubleshooting*: Because the systems are flexible you will probably run into situations where you try a new transaction and it doesn't work the way you thought it would. The vendor, with on line access, can see what you did and tell you how to do it correctly. At times production will crash and they can walk you though the restore and rerun.
- *Training*: In our case, we have had to bring the vendor back in a number of times to train the computer production personnel because of rapid turn over of people in that area.
- *User Group*: The user groups bring a wide variety of ideas for changes and improvements to the system. They push the vendor to keep the system up with current technology. Most system improvements will come through this group. Maintenance agreements, paid by all, cover the cost of most, if not all, of these improvements. Look for a system with an active user group and a responsive vendor.
- *System Updates and New Releases*: The system should be updated at least annually with minor improvements and every few years have a new release with some major improvements.
- *Interfaces*: In most cases, if you have the vendor write your interfaces the vendor is responsible to ensure that the interfaces work in the updates and new releases. Some users do not install the updates or new releases because of the cost to themselves to modify the interfaces or modifications that they made. Let the vendor do the interfaces and any needed modifications. It is a one time cost and may be less costly than in-house work because of their knowledge of the system. It should not affect what you would pay for the on-going maintenance agreement.

SUMMARY

Commercial systems are readily available in a wide range of capabilities and cost. All are less costly to acquire and install than building one from scratch. Most are flexible in how they operate to meet the needs of a variety of users. With a cross section of users the vendor receives a broad range of input from which to constantly update the system. Those looking for a new system should look into the commercial systems before trying to build one.

NORTHEASTERN STATES EQUIPMENT MANAGER CONFERENCE

Ronald D. Doemland
Pennsylvania Department of Transportation

The first Northeastern States Equipment Manager Conference was co-hosted by the Pennsylvania Department of Transportation and the Pennsylvania Turnpike Commission. The conference was held in Harrisburg, Pennsylvania, September 12-14, 1995. Representatives from the following transportation agencies were in attendance: New Jersey, Connecticut, Delaware, Ohio, Vermont, Pennsylvania, Maine and the Pennsylvania Turnpike Commission.

Agenda topics included:

- Mechanic and Operator Training.
- Pennsylvania's Alternative Fuels Program.
- Preventive Maintenance Quality Assurance.
- Equipment Refurbishing.
- Biodiesel Fuel.
- Spreader Evaluations.
- Equipment Specifications Roundtable:
  - Snow Plows,
  - Dump Trucks,
  - Loaders,
  - Patching Equipment,
  - Tractor Mowers,
  - Joint Sealing Machines, and
  - Truck Mounted Attenuators.
- Winter Operations Roundtable.

A tour of Pennsylvania's Equipment Operator Training Site at Ft. Indiantown Gap also was provided. All in attendance agreed the 1st Northeastern Equipment Managers Conference was a success. It was decided to stage another conference in the Spring or Fall of 1997. Connecticut will host the conference if approvals can be obtained. Delaware will serve as a backup. If Connecticut is unable to host the 1997 conference, Ron Doemland will contact other states who did not attend the 1995 conference to see if they can host a 1997 conference. Delaware will remain the backup.

1995 MIDWESTERN STATES EQUIPMENT MANAGEMENT CONFERENCE

Brandon C. Long and Richard W. Hunter
Illinois Department of Transportation

SUMMARY

The 7th Midwestern States Equipment Conference was hosted June 5-7, 1995 in Lincoln, Nebraska by the Nebraska Department of Roads. Participating states were Illinois, Iowa, Kansas, South Dakota, North Dakota, Missouri, Wisconsin and Nebraska. The following is a brief summary of discussion topics and information reported during the meeting.

- *Salt Storage and Purchase*—Wisconsin presented the results of a study on the enlargement of existing and the construction of new salt storage sites. The comprehensive plan included the capability of salt delivery by a minimum of two of three delivery alternatives: truck, barge or rail. It included the criteria for determining the facility size, location and other construction parameters, and measures established for the emergency distribution of salt to other locations.
- *RF Low Band Interference* - Illinois outlined the problems resulting from RF interference in the low-band communication system resulting from the 1992 thru 1994 Allison World Transmission. The resulting emissions from the microprocessor reduced the effective operating range of the two-way radio by as much as 60% by locking the radio's receiver until a stronger signal overrode the noise. The testing procedures were outlined and the filter used to suppress the noise were discussed.
- *Snowplows* - Minnesota discussed the use and their success using the Frink Reverse-a-cast plow. Iowa and Nebraska have purchased these and expect to purchase more. Iowa distributed information on the snowshield that is inexpensive and easily fitted on existing plows and aids in operator visibility by redirecting the snow coming over the moldboard shield.
- *MUTCD Regulations* - Kansas questioned the compliance to MUTCD regulations with respect to using TMA's on slow moving operations on two-lane roadways. No one in attendance had heard of any regulation mandating this use.
- *Equipment Management Systems* - This topic could be the sole agenda for an entire meeting! The state of Nebraska asked questions pertaining to the parameters used in other midwestern states in the design of their systems. The best systems seemed to come from states that designed and built their systems in-house. The other common expression was to design for future expansion and ensure all the needs of the users could be met.
- *Communications* - Several states reported the use of cellular phones in select positions in their maintenance operations. All commented favorably on their effectiveness during emergency operations. Columbia County Wisconsin is using a ground speed spreader control with a global positioning device in an experimental study.
- *Cooperative Procurement* - Minnesota presented their state program that allows other governmental entities to purchase from state contracts. Their system also allows input into the specification of the product. The practice saves money and improves the quality of the equipment purchased.
- *Off-Shore Equipment* - Mr. Heedum gave a slide presentation of equipment and recycling efforts used in Japan. These included rubber recycling, computerized communication center, wind tunnel plow and spreader testing, remote brine spreading on bridge decks, and rubber mounted moldboards on snowplows to reduce shock.

HOST STATE FACILITY AND EQUIPMENT TOUR

A portion of the meeting was spent touring the Nebraska Tractor Testing facilities at the University of Nebraska. Tractors are evaluated for pulling and PTO horsepower, and tractive effort. They also measure engine noise and cab noise levels. These findings are published and have become the standards several states use as a part of their tractor specifications. We visited the central garage and receiving location for the Nebraska Department of Roads. There we saw equipment ranging from large bridge inspection cranes, snow route tandems, sign installation trucks, light-duty trucks, mowing equipment and alternative alcohol fueled vehicles.

FUTURE MEETINGS AND PLANS

Ohio agreed pending upper management approval to host the meeting in 1996. The meeting will be held in August

to prevent conflict with other national meetings. Tentative future plans include: Indiana in 1997, North Dakota in 1998, and South Dakota in 1999. These meetings will be held the first week in June each year and are dependent on the host state management concurrence.

1996 SOUTHEASTERN STATES EQUIPMENT MANAGERS MEETING

Bill Holmes
Alabama Department of Transportation

SUMMARY

The 10th Annual Southeastern States Equipment Managers meeting was held April 15-18 in Frankfort Kentucky. Twelve states were represented with 23 attendees. Arkansas was the only state not attending due to a freeze in travel. Industry representatives and representatives from the attending states discussed the following topics.

- *Alternate Fuel Vehicles* - A subject of continuing interest is alternate fuel vehicles. Input was provided from both Navistar and Ford on their plans for medium duty trucks. Both indicated that most of their development efforts were aimed at natural gas, which both considered the most cost effective of the alternate fuel options. All in attendance expressed concern over the lack of infrastructure to support refueling for alternate fuel vehicles. It was also generally agreed that there were no totally advantageous alternate fuels. With the exception of Texas, most southeastern states are taking a go-slow, wait and see approach to alternate fuel vehicles.
- *Annual Inspection of Aerial Trucks* - The Mississippi representative presented an interesting report on different states' efforts to comply with inspection requirements for aerial trucks. Six states have in existence, or are developing a contract for annual inspection services from an independent testing agency. Although all states had a keen interest in annual inspections, some have not taken action to implement these inspections.
- *Contractor Operated Warehouses* - Kentucky briefed on their experience with contractor warehouses operated by NAPA. The concept is similar to that operated by the federal government on military installations. Contractor operation of warehouses requires some significant volume and the group discussion voiced many pros and cons to such a concept.
- *Flat Rate Standards for Heavy Equipment* - Champion and John Deere presented an interesting briefing on flat rate standards that are available for heavy equipment. These standards patterned after automotive flat rates are available from both Champion and John Deere. John Deere also provided the group with information and a catalog of videos that can be used for service and safety training.
- *New Product Evaluation* - Texas provided the attendees with an overview of their procedures for product evaluation. They provided their written policy and application form for new product consideration. Texas also shared their research on so called "gas saving" products. The bottom line on these products was that they either didn't work or could not pass EPA clean air standards.
- *800 MHz Communications System* - Kentucky shared their experience with their 1-800 trunking communications system. Most states related interest within their DOT for such systems. The advantages and flexibility of these systems were discussed along with the massive capital investment required.
- *Standard Vehicle Colors* - The Mississippi representative presented a comparative study that his state had done on equipment painting. The scope of this study was nationwide. While white is increasing in use, the various orange and yellow colors are still high demand colors in some states for work zone vehicles. As in past discussions, suggestions for standardization were met with heated opposition.
- *Vehicle Buy-back* - Louisiana reported on their buy back program and the results of the past year. They have mowing tractors, graders, and trac and rubber tire backhoes under this program. All equipment is on a 100% or greater buy back except for the trac backhoes. Louisiana feels this is an extremely effective program providing new equipment at low cost, and requires only increased coordination/control efforts to manage the program.
- *Equipment Utilization* - South Carolina presented a study they had done comparing management techniques for controlling vehicle utilization. This covered reporting systems, utilization standards, management responses to high and low utilization, and actual utilization for selected equipment.
- *Comparison of Fleet Operations* - Florida reported on an extensive survey that they have done on comparing fleet operations throughout the southeast. The study covered organizational layout, tasks/responsibilities, manning, information systems, specifications, department demographic information and response to numerous opinion questions. This data related to all organizational

levels. Due to the magnitude of this study some of the results will be held over and reported on at the next regional meeting.

- *Petroleum Product Specification Comparison* - Georgia representatives presented a study they had compiled of specification requirements for petroleum products. There was great interest from the group in viewing other states contracts. There also was an extended discussion on how to specify motor oils so that a quality product could be obtained. All participants agreed to require that the vendor product be certified and stamped as an API Licensed Product.

SPECIAL TOUR

The meeting location offered an excellent opportunity to visit the Ford truck plant in Louisville. This was an informative tour and a chance for all to talk to production facility managers. It also provided a close-up look at Ford's new Louisville line of trucks.

PLANS FOR FUTURE MEETINGS

The 1997 meeting will be held in Panama City, Florida about a month later than this year's meeting. We have had significant turnover in personnel within our group and it is encouraging to see that the new people value these meetings as much as the original representatives did.

WESTERN STATES HIGHWAY EQUIPMENT MANAGERS CONFERENCE, PHOENIX, ARIZONA, 1995

Dwight R. Berkey
Oregon Department of Transportation

The Western States Highway Equipment Managers Conference was held in Phoenix, Arizona on September 27-29, 1995. Nine western states sent representatives to the conference. They were Montana, Nevada, Wyoming, Oregon, Arizona, Utah, Idaho, Washington and Colorado. California, Alaska, Hawaii, Texas and New Mexico were unable to attend.

The Western States group was formed in 1969 by Oregon, Washington and California equipment managers interested in fostering advancement in their field and sharing knowledge and experiences in an endeavor to become more efficient and effective. The conference's main topics included fleet administration, personnel matters and training, equipment specifications and procurement, equipment usage and allocation, snow removal equipment, alternative fuels, equipment support and repair costs. Following are brief summaries of the topics discussed during the conference.

- *Fleet Administration* - Discussed were the pros and cons of fleet privatization, downsizing and right-sizing, repair shop outsourcing, and data used to make prudent fleet management decisions. The group shared wisdom gained through shrinking tax revenues.
- *Personnel Matters and Training* - Caltrans, even though they did not attend the meeting, provided the information regarding several methods of driver and equipment operator training. They have an equipment-training academy that serves several operating functions within the department to train personnel on maintenance, care and operation of equipment. Oregon has a similar training academy and shared that information with the group. Other topics included wages, staffing levels, classifications, and career ladders.
- *Equipment Specifications and Procurement* - Western States Highway Equipment Managers discussed their equipment replacement methodology as well as procurement concerns and life cycle costing methods. Arizona is required by statute to use total-cost bidding. Idaho uses total-cost bidding with guaranteed buy-back. Idaho has purchased motor graders, loaders, tractor-trailers, and backhoes using the total-cost bidding and guaranteed buy-back method. Idaho figures they have saved almost $4 million dollars in maintenance and depreciation over the last four years. Also, several states shared their tandem-axle wing plow truck specifications.
- *Equipment Usage and Allocation* - Discussion under this topic included how equipment usage is collected and used to allocate fleet to end-users. Most states seem to use an equal dollar amount allocated to their customers. Declining revenues have affected fleet replacement and do not seem to meet the need in most states.
- *Snow Removal Equipment and Procedures* - Information was presented with discussion on the following topics: rear crash attenuators on snowplows, underbody (mid-mount) snowplows, liquid de-icers, side-discharge belt snow loaders, strobe versus rotolight usage during snow removal operations, power-angling snowplows, salt-dispensing controllers, infra-red sensors to detect accurate road temperatures, auger/sanders, snowplowing speed, and engine transmission life and cost in heavy-duty snowplow trucks.
- *Alternative Fuels* - There was much discussion about the advantages and disadvantages, cost, usage, converting equipment and fueling sites including remote locations.
- *Equipment Support and Repair Costs* - The group discussed personnel support costs to maintain vehicles along with costs relating to automatic transmissions in plow trucks, cost per mile, overhead, fuel and insurance, operating and repair costs.

The Western States group also discussed many miscellaneous equipment and repair related topics. This forum has been invaluable over the years in promoting information sharing, good will and contacts with other states. A post-conference tour provided the attendees with a four-hour tour of the General Motors desert proving ground facility. The equipment managers were able to participate first-hand in the anti-lock brakes and handling demonstration.

The 1996 Western States Highway Equipment Managers Conference is to be hosted in September 1996 by the Nevada DOT in Reno. As always, this group encourages and invites other interested states to attend. The group is looking forward to another successful conference in 1996.

APPENDIX A: FINAL PROGRAM

Sunday, June 23, 1996

12:30 - 3:30 p.m. **PRE-WORKSHOP TOUR**

Workshop and Spouse/Guest Program participants are invited to tour the New York State Department of Transportation's Equipment Repair Facility in North Syracuse. Vans, compliments of NYSDOT, will depart the Sheraton University Hotel and Conference Center at 12:30 p.m. and return at approximately 3:30 p.m.

4:00 - 7:00 p.m. **REGISTRATION & INFORMATION**

6:00 - 7:00 p.m. **RECEPTION (Hosted)**

Monday, June 24, 1996

7:30 a.m. - 5:00 p.m. **REGISTRATION & INFORMATION**

7:30 - 8:30 a.m. **CONTINENTAL BREAKFAST**

8:30 - 9:00 a.m. **OPENING SESSION**

Doug Nielsen, *Arkansas State Highway and Transportation Department*, and *Chair of TRB Committee on Equipment Maintenance*, presiding

WELCOMING REMARKS

John B. Daly, *Commissioner of Transportation, New York State Department of Transportation*
Harold J. Brown, *New York Division Administrator, Federal Highway Administration*
Charles E. Moynihan, *Region 3 Director, New York State Department of Transportation*
Edward G. Fahrenkopf, *Director of Equipment Management Division, New York State Department of Transportation*

9:00 - 10:00 a.m. **GOVERNMENT REGULATIONS: THE CHANGING SCENE**

Leland D. Smithson, *Iowa Department of Transportation*, presiding
Challenges Faced by Truck Engineers in the Mid 1990's, Ken Kelley, *Roads and Bridges Magazine*
Alternative Fuels Report, Glenn Hagler, *Texas Department of Transportation*

10:00 - 10:30 a.m. BREAK

10:30 a.m. - Noon **INTERNATIONAL EQUIPMENT TECHNOLOGY**

Richard W. Hunter, *Illinois Department of Transportation*, presiding
Swedish and Norwegian Equipment, John Howard, *Minnesota Department of Transportation*
Learning From Abroad—Winter Maintenance Program, Leland D. Smithson, *Iowa Department of Transportation*
Minnesota Department of Transportation/Finnish National Road Administration -- Maintenance Technology Exchange Partnership, Päivi K. Martikainen and John H. Scharffbillig, presented by John Howard, *Minnesota Department of Transportation*

Noon - 1:00 p.m. LUNCH

1:00 - 2:45 p.m. **HUMAN RESOURCE MANAGEMENT**

Thomas H. Maze, *Iowa State University*, presiding

Self-Directed Highway Maintenance Teams, Roger McAniff, *Strategic Performance Consulting* and Dale Allen, *Oregon Department of Transportation*, presented by Jerry Baggett, *Oregon Department of Transportation*

Minnesota Department of Transportation Maintenance Operations Research Program, Päivi K. Martikainen and Paul F. Keranen, presented by John Howard, *Minnesota Department of Transportation*

New York State DOT's Performance Measures, Steve Wilcox, *New York State Department of Transportation*

PennDOT's Performance Measures, Ronald D. Doemland, *Pennsylvania Department of Transportation*

2:45 - 3:15 p.m. BREAK

3:15 - 5:15 p.m. **SAFETY**

Dwight R. (Dick) Berkey, *Oregon Department of Transportation*, presiding

Economic Evaluation of Truck Collision Warning Functions, James York and Thomas H. Maze, *Iowa State University*

Truck Mounted Attenuators and *NCHRP Report 350*, J. M. Essex, *Energy Absorptions Systems, Inc.*

Emergency Warning Light Technology, Robert Cameron, *Whelen Engineering*

Forward Lighting Configurations for Snowplows, Peter Bajorski, *New York State Department of Transportation*

Tuesday, June 25, 1996

7:00 a.m. - Noon **REGISTRATION & INFORMATION**

7:00 - 8:00 a.m. **CONTINENTAL BREAKFAST**

8:00 - 10.00 a.m. **SPECIALTY EQUIPMENT**

John M. Burns, Jr., *North Carolina Department of Transportation*, presiding

Bridge Inspections and the Equipment It Demands, Milton J. Luttrell, III, *Aspen Aerials, Inc.*

Thermoplastic Pavement Marking Technology and Equipment, Murray Richardson, *Stimsonite, Inc.*

Custom Wiring Systems for Specialty Trucks, Stuart A. Owades, *Wired Rite Systems, Inc.*

A Simplified Heavy-Duty Sand Spreader: Phase 1 - Design Concept, Samuel Fields, *Oregon Department of Transportation*

10:00 - 10:30 a.m. BREAK

10:30 a.m. - Noon PURCHASING AND LEASING

Arlen T. Swenson, *Simon North American Fire*, presiding

Total Cost Equipment Purchasing, H. Lee Hax, *South Carolina Department of Transportation*

Total Cost Purchasing - A Manufacturer's Perspective, Coke Mattingly, *Caterpillar, Inc.*

North Carolina Tire Recap Program, John M. Burns, Jr., *North Carolina Department of Transportation*

Noon - 1:00 p.m. LUNCH

1:00 - 4:00 p.m. **FUTURE EQUIPMENT TECHNOLOGY**

Edward H. Adams, *Kentucky Transportation Cabinet*, presiding

Conceptualization of the Future Highway Maintenance Vehicle, Leland D. Smithson, *Iowa Department of Transportation*, and Duane E. Smith, *Iowa State University*

Application of New Technologies in Truck and Bus Engineering, Rick Malecki, *Navistar Transportation Corp.*
Using Automatic Transmissions to Meet Your Needs, Chris Collet, *Allison Transmission*

2:30 - 3:00 p.m. BREAK

Carbide Tooling in Road Maintenance Technology, Terry Manway, *Kennametal, Inc.*
Application of Robotic Devices, Thomas H. West, *California Department of Transportation*

5:00 - 11:00 p.m. **DINNER AND ENTERTAINMENT AT BECK'S GROVE DINNER THEATER**

Wednesday, June 26, 1996

7:00 a.m. - Noon **REGISTRATION & INFORMATION**

7:00 - 8:00 a.m. **CONTINENTAL BREAKFAST**

8:00 - 9:00 a.m. **DEVELOPMENTS IN EQUIPMENT MANAGEMENT SYSTEMS**
Ronald D. Doemland, *Pennsylvania Department of Transportation*, presiding
Panel Discussion
The panel discussion will focus on the past, present and future characteristics of equipment management systems.
Panel Members, TBD

9:00 - 10:00 a.m. **REPORTS FROM REGIONAL EQUIPMENT MANAGERS MEETINGS**
Robert W. Kuenzli, *Consultant*, presiding
Northeastern Region, Ronald D. Doemland, *Pennsylvania Department of Transportation*
Midwest Region, Richard W. Hunter, *Illinois Department of Transportation*
Southeastern Region, Francis E. Allred, *Alabama Department of Transportation*
Western Region, Dwight R. (Dick) Berkey, *Oregon Department of Transportation*

10:00 - 10:30 a.m. BREAK

10:30 - 11:30 a.m. **EQUIPMENT RESEARCH ISSUES**
Doug Nielsen, *Arkansas State Highway Transportation Department*, and *Chair of TRB Committee on Equipment Maintenance*, presiding

11:30 - 11:45 a.m. **CLOSING REMARKS**
Doug Nielsen, *Arkansas State Highway Transportation Department*, and *Chair of TRB Committee on Equipment Maintenance*
Edward G. Fahrenkopf, *New York State Department of Transportation*

1:30 - 4:00 p.m. **POST-WORKSHOP TOUR**
Workshop and Spouse/Guests Program participants are invited to tour the Chrysler New Process Gear Plant. Vans, compliments of NYSDOT, will depart the Sheraton University Hotel and Conference Center at 1:30 p.m. and return at approximately 4:00 p.m.

ACKNOWLEDGMENTS

Program Logistics, New York State Department of Transportation: Edward G. Fahrenkopf and Janet Manning
Technical Program Committee: Richard W. Hunter, Chair, Leland D. Smithson and Arlen T. Swenson

APPENDIX B: WORKSHOP PARTICIPANT LIST

Edward H. Adams
KY Transportation Cabinet
Room 701
State Office Building
Frankfort, KY 40622

Randy J. Anderson
Clark County Highway Dept.
801 Clay Street
Neillsville, WI 54456

Fred W. Austin
Warren County DPW
P.O. Box 10
Warrenburg, NY 12885

Jerry H. Baggett
Oregon DOT
P.O. Box 399
Prineville, OR 97754

Peter Bajorski
NYS DOT
Transp. R&D Bureau
Bldg. TA, Rm. 600
Albany, NY 12232-0869

Dwight R. Berkey
Oregon DOT
2800 State Street
Salem, OR 97310

Douglas Bernard
Energy Absorption Systems, Inc
306 7th Street, N.E.
Washington, DC 20002

John W. Bowman
New Jersey DOT
999 Parkway Avenue
Trenton, NJ 08625

Harold J. Brown
FHWA
Leo W. O'Brien Fed Bldg
Clinton & N. Pearl, 9 Fl
Albany, NY 12207

John M. Burns, Jr.
North Carolina DOT
4809 Beryl Road
Raleigh, NC 27606

Robert D. Cameron
Whelen Engineering Co., Inc.
Route 45, Winthrop Road
Chester, CT 06412-0684

Chris Collet
Allison Transmission
P.O. Box 894
Indianapolis, IN 46206-0894

George S. Combes
VT Agency of Transporation
133 State Street
Central Garage
Montpelier, VT 05633

David J. Coyne
Maryland State Hwy. Admin.
Office of Maintenance
7491 Connelley Drive
Hanover, MD 21076

Frederick P. Crozier
Maryland State Hwy. Admin.
District 6
1251 Vocke Road
LaVale, MD 21502

John B. Daly
New York State DOT
1220 Washington Avenue
Building 5, State Office
Albany, NY 12232

Joseph Darling
New York State DOT
1220 Washington Avenue
Albany, NY 12232-0319

Don A. Davidson
MO Highway and Transp. Dept.
P.O. Box 270
Jefferson City, MO 65102

Ronald D. Doemland
Pennsylvania DOT
17th & Arsenal Blvd.
Harrisburg, PA 17120

Edward G. Fahrenkopf
New York State DOT
1220 Washington Avenue
Albany, NY 12232-0319

Samuel Fields
Oregon DOT
2800 State Street
Salem, OR 97310
503/986-2725

David H. Fluharty
University of New Hampshire
33 College Road
Kingsbury Hall
Durham, NH 03824-3591

Van M. Frazier
Georgia DOT
Office of Equip. Mgmt.
7565 Honeycreek Court
Atlanta, GA 30058

Bennett C. Gardiner
NY State DOT
73 Frederick Street
Binghamton, NY 13901

Edward R. Glasgow
New York State DOT
5450 South Bay Road
N. Syracuse, NY 13212

Bill Gooch
Utah DOT
4501 S. 2700 W.
Salt Lake, UT 84119

Glenn R. Hagler
Texas DOT
125 E 11th
Austin, TX 78701-2483

Hugh L. Hax
South Carolina DOT
955 Park Street
Columbia, SC 29072

William Hitchcock
Millcreek Township
3608 W. 26th Street
Erie, PA 16505

William C. Holmes
Alabama DOT
1409 Coliseum Blvd
Montgomery, AL 36130

John E. Howard
Minnesota DOT
6000 Minnehaha Avenue S.
Office of Maintenance
St. Paul, MN 55111-4014

Raymond J. Hull
NY State Thruway Authority
200 Southern Blvd.
Office of Equip & Invent.
Albany, NY 12201-0189

Richard W. Hunter
Illinois DOT
2300 S. Dirksen Parkway
Room 009
Springfield, IL 62764

Russell L. Ingram
Kentucky Dept. of Highways
Division of Equipment
1234 Wilkinson Blvd.
Frankfort, KY 40622

Magnus V. Johannsson
Public Roads Administration
Borgartun F, 105
Reykjavik,
ICELAND

Willis D. Kates
Delaware DOT
Equipment Section
P.O. Box 778
Dover, DE 19903-0778

Daniel M. Keller
Cattaraugus County DPW
214 Main Street
Little Valley, NY 14755

Ken Kelly
Roads & Bridges Magazine
22638 Alexandrine
Dearborn, MI 48124

George B. Kinker
VDOT
1401 East Broad Street
Richmond, VA 23219

J.T. Kral
NY State DOT, Equip Mgmt Div
Harbor Lock Road
Utica, NY 13502

Larry Kuhn
Navistar Transportation Corp
2911 Meyer Road
Medium Trucks & Buses
Fort Wayne, IN 46801

Robert G. Lannert
MO Hwy & Transp Dept
P.O. Box 270
Jefferson City, MO 65102

Anthony Maieli
New York State DOT
375 Carleton Avenue
Equipment Mgmt Division
Central Islip, NY 11722

Janet Manning
New York State DOT
1220 Washington Avenue
Albany, NY 12232-0319

Tom Maze
Ctr for Trans Rsch & Education
2625 N. Loop Dr, Ste 2100
Iowa State University
Ames, IA 50010

Russell McCurdy
NYS DOT - Equipment Management
2797 Clover Street
Pittsford, NY 14534

William R. Moltion
Onondaga County DOT
1100 Civic Center
421 Montgomery Street
Syracuse, NY 13202

Richard J. Knapp
NYS DOT
Region 7 Equipment Mgmt.
22422 NYS Route 242
Watertown, NY 13601

Robert W. Kuenzli
Consultant & Analyst
4386 Camellia Drive South
Salem, OR 97302-2712

Chuck Lamb
Wired Rite Systems, Inc.
5468 Skylane Blvd
Santa Rosa, CA 95403

Milton J. Luttrell, III
Aspen Aerials, Inc.
4303 West 1st Street
P.O. Box 16958
Duluth, MN 55816-0958

Matthew C. Maize
State Highway Administration
7491 Connelley Drive
Hanover, MD 21076

Coke Mattingly
Caterpillar, Inc.
Peoria, IL 61629-1230

Michael D. McClurkin
PA Turnpike Commission
P.O. Box 67676
Harrisburg, PA 17106-7676

Clifford C. McMullen
Roy Jorgensen Associates
P.O. Box 70
Buckeystown, MD 21717

Charles E. Moynihan
New York State DOT
333 East Washington St.
Syracuse, NY 13202

Robert C. Near
New York State DOT
272-278 Violet Avenue
Poughkeepsie, NY 12601

Doug Nielson
AR State Hwy & Trans Dept
P.O. Box 2261
Little Rock, AR 72203

R.J. Northrup
New York State DOT
7000 CO Route 70A
Hornell, NY 14843

William S. Park
New York State DOT
4717 Southwestern Blvd.
Hamburg, NY 14075-1999

David H. Rhodes
Wired Rite Systems, Inc.
5468 Skylane Blvd
Santa Rosa, CA 95403

G. Michael Smith
New York State DOT
1220 Washington Avenue
Albany, NY 12232-0319

Walter R. Smith
NY State Thruway Authority
200 Southern Blvd.
Office of Equip & Invent.
Albany, NY 12201-0189

Leland D. Smithson
Iowa DOT
800 Lincoln Way
Amos, IA 50010

Paul C. Stone
Nova Scotia DOT & Public Works
P.O. Box 409
Bridgewater, B4V 1M1
NOVA SCOTIA

Arlen T. Swenson
Simon-LTI
64 Cocalico Creek Road
Ephrata, PA 17522

Walter J. Tennant, Jr.
Cortland Cnty Highway Dept.
P.O. Box 5590
Cortland, NY 13045

Ferdinand Theriot
LA DOTD
1701 Foss Drive
Baton Rouge, LA 70802-3567

Douglas L. Tily
Onondaga County DOT
1100 Civic Center
421 Montgomery Street
Syracuse, NY 13202

Bruce J. Trexler
Onondaga County DOT
1100 Civic Center
421 Montgomery Street
Syracuse, NY 13202

Edward J. VanWormer
New York State DOT
21 Ninth Street
Waterford, NY 12188

Ron Vititoe
Stimsonite, Inc.
1855 Plymouth Road, NW
P.O. Box 94108
Atlanta, GA 30318

Frederick C. Walden
Jefferson County Hwy Dept.
21897 County Road 190
Watertown, NY 13601

Allan D. Wells
CALTRANS - CA DOT
34th Street & Stockton
P.O. Box 160048
Sacramento, CA 95816

Thomas H. West
University of CA/CA DOT
1001 Academic Surge Bldg
Davis, CA 95616-5294

Steve Wilcox
New York State DOT
1220 Washington Avenue
Transp Maintenance Div
Albany, NY 12232