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July 16–20, 2006
Charleston, South Carolina

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Preface

This publication contains papers presented at the 11th AASHTO–TRB Maintenance Management Conference held in Charleston, South Carolina, July 16-20, 2006. The objective of this series of conferences is to provide a forum every three to four years for the exchange of new ideas and developments in the maintenance and operations management of transportation facilities. The conference was hosted by the South Carolina Department of Transportation, and jointly sponsored by the Transportation Research Board, the American Association of State Highway and Transportation Officials, and the Federal Highway Administration of the U.S. Department of Transportation. It was integrated into the Annual AASHTO Highway Subcommittee on Maintenance meeting and includes papers on outsourcing, pavements, roadside, winter operations, bridges, maintenance management systems, quality assurance, equipment, work force development, traffic services & safety.

The views expressed in the papers contained in this publication are those of the authors and do not necessarily reflect the views of the Transportation Research Board, the National Research Council, or the sponsors of the conference. The papers have not been subjected to the formal TRB peer review process.

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The technical program was developed through the joint efforts of Chairman, Vice-Chairman, Secretary and Task Force and Focus Group Leaders of the AASHTO Highway Subcommittee on Maintenance, and members of TRB Maintenance Section (AHD00).

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Outsourcing Maintenance Activities

PART 1: OUTSOURCING MAINTENANCE ACTIVITIES

Outsourcing Maintenance Management
A Field Perspective

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A research project was conducted by Clemson University for the South Carolina Department of Transportation (SCDOT) to examine the relative merits of outsourcing highway maintenance activities as opposed to performing those activities with in-house forces. The research project examined the costs associated with maintenance work performed within the state for 20 maintenance-related activities in FY 2003–2004. The unit costs for activities including drain pipe installation, mowing, sign installation, and full-depth patching were found to be about the same. Some activities—drainage structure replacement, guardrail installation, and raised pavement marker installation—were difficult to compare because projects of major magnitude were let to contract whereas smaller magnitude projects were performed in-house. Then too, some activities were performed exclusively either by contract or in-house in FY 2003–2004. The research methodology also included workshops conducted in all seven SCDOT district offices to examine subjective field perspective factors that impact local decisions as to whether or not it is appropriate to outsource various maintenance activities. District personnel cited equipment availability, local contractor expertise, SCDOT inspection and contract administration capabilities, seasonal work fluctuations, and the need for immediate SCDOT response to specified problems among their decision factors. Workshop participants also suggested that improvements be made to the outsourcing contracts to give them more leverage with respect to specification conformance. Because other state transportation agencies may encounter similar difficulties in fully executing cost comparisons, it is suggested that outsourcing policy decisions be based upon a through examination of the equally important subjective field perspectives discussed in this paper.

INTRODUCTION

Highway maintenance outsourcing, when utilized by state departments of transportation (DOTs), has been met with mixed success. An excellent compendium of the experiences of other states was documented in a paper, Synopsis of WSDOT'S Review of Highway Maintenance Outsourcing Experience, presented by Nicole Ribreau at the 83rd Annual Meeting of the Transportation Research Board in January 2004. In reference to the concept of maintenance outsourcing the author states that her research found cases where costs may have gone up instead of down, services deteriorated rather than improved, administrative and supervisory arrangements proved problematic, and contractor failures left states scrambling to provide services or caught in the distraction of litigation (*1*).

This paper cited numerous examples of less-than-positive experiences in other states. Oklahoma cancelled its pilot program and has experienced many litigation problems. Texas is evaluating whether or not to renew its contracts. Massachusetts did not expand a much-criticized program—an audit report stated that a pilot program actually resulted in a loss of over $1 million. Virginia has let to contract maintenance services for 23% of its Interstate system, but debate continues as to whether or not cost savings can be documented. A major conclusion of the paper states that audits and other after-the-fact reviews of state highway maintenance outsourcing programs have broadly shown that initial claims of projected cost savings and service benefits are, at best, difficult to verify and, at worst, demonstrably overstated (*1*).

The Florida DOT (FDOT) has been mandated to execute an employee reduction plan and examine privatization as a means of cost reduction. The percentage of FDOT maintenance work performed by private contractors was estimated to be 74% in 2003. Department managers compared the unit costs for services such as mowing, embankment repairs, and shoulder repairs performed by employees to prices bid by private contractors and determined that in many cases private contractors were providing services at a lower unit cost than in-house employees. This allowed the FDOT to reduce its budget request for highway maintenance by $5.9 million in FY 2002–2003 (*2*).

The current trends in outsourcing a wide range of transportation agency activities is summarized in *NCHRP Synthesis 246: Outsourcing of Highway Facilities and Services* (*3*). The report indicates that 21 of 30 states surveyed indicated all or some part of highway maintenance work was outsourced. As noted in this report and elsewhere, the factors that should be considered before implementing an outsourcing program include

- Limited in-house resources,
- Need for specialized expertise or equipment,
- Better quality,
- Statutory requirements or agency policies,
- Seasonality of work, and
- Contractor availability.

Although not addressed in this paper, the concept of transportation asset management, of which maintenance management is but one component, is gaining in popularity. The NCHRP report: Transportation Asset Management Guide (*4*) briefly discusses outsourcing of maintenance activities and stresses factors to consider when analyzing the tradeoffs between in-house and outsourced work, which include

- Availability of accurate cost data for comparing in-house versus outsourcing;
- Internal costs and expertise to administer outsourcing contracts; and
- A “safety net” if public employees are displaced by a private-sector work force.

This publication also cites as examples the turnpike maintenance experiences of FDOT, the $131 million fixed-price contract experience of the Virginia DOT, the phased implementation experience of the Massachussets Highway Department, and the managed competition experience of the Iowa DOT.

This paper summarizes a research project recently undertaken for the South Carolina DOT (SCDOT) by Clemson University, the primary objective of which was to evaluate the advantages and disadvantages of outsourcing more or less maintenance work than what is currently undertaken by in-house forces as opposed to outsourcing contract. The research examined relative costs as well as a number of the important decision factor issues cited in the literature.

RESEARCH METHODOLOGY

In an effort to examine the relative advantages and disadvantages of maintenance outsourcing, the Clemson University research project utilized a methodology consisting of the following tasks:

- Literature review,
- Questionnaire survey of other state agencies,
- Interviews with key SCDOT personnel,
- Compilation and analysis of SCDOT in-house and outsourced contract cost data,
- A series of workshops held in all seven district offices to document decision factor issues, and
- Survey of contractors performing outsourced maintenance within the state.

This paper will address only the cost data analysis and the deciding factor issues that were fully explored at the district workshops. Cost data for in-house maintenance activities is captured in the SCDOT highway maintenance management system (HMMS). Cost data for outsourced contracts resides within both the SCDOT procurement department (contracts less than $50,000) and the SCDOT construction office (contracts more than $50,000).

What is termed in this paper as “decision factors” are the field perspectives of maintenance professionals that include such issues as equipment availability, contractor and agency expertise, demands of seasonal work, contractor quality, required agency oversight and inspection, contractor availability, and public perceptions. These factors were fully examined at seven half-day workshops that were conducted in each SCDOT district office. Each workshop, conducted by the Clemson University research team, was attended by approximately 20 SCDOT district personnel. To encourage candor within the workshops, SCDOT supervisory personnel, other than those working within the district, were not permitted to attend.

The scope of the overall research project included 17 distinct maintenance activities. It was soon discovered that no meaningful comparisons could be made for a number of those activities because they have historically been either exclusively let to contract, or exclusively performed by in-house forces. Activities for which meaningful comparisons could be made are discussed in the following sections of this paper.

COST DATA COMPARISONS

As part of the research project described herein, the Clemson University research team solicited data from SCDOT in an attempt to compare the cost of work performed in house and work let to contract. FY 2003–2004 data were obtained from the SCDOT HMMS system to compile in-house activity unit costs, and from the SCDOT construction and procurement offices to obtain contracted activity costs. The activities for which a meaningful cost comparison could be made are listed, with in-house and outsourced units, in Table 1.

TABLE 1 In-House versus Outsourced Costs for Selected SCDOT Maintenance Activities, FY 2003–2004

Maintenance Activity	Unit of Measure	In-House Unit Cost	Average Outsourcing Unit-Cost
Drainage structures	Each	$515.67	$2,545.84
Drainage pipe	LF	$39.13	$31.08
Tree trimming	SH mile	$201.46	$733.69
Mowing	Acre	$23.65	$24.29
Chip sealing	Square yard	$0.31	$0.77
Guardrail installation	LF	$34.81	$11.88
Pavement striping	LF	$0.19	$0.03
Raised pavement markers	Each	$17.28	$2.61
Sign installation	Each	$25.28	$35.31
Full depth patching	Square yard	$25.12	$33.25
Bridge replacement	Square foot	$133.49	$65.00

Drainage Structure Installation

The majority of drainage structure work includes installing, repairing, and upgrading catch basins. The bulk of drainage work is performed with in-house forces, however districts often outsource the installation of major structures, or structure upgrades. Nine drainage structure contracts were examined from procurement, which showed a significant cost difference when compared to in-house costs. The average unit cost to perform this activity with in-house forces was $515.67, as compared to $2545.84 when let to contract. Again, the significant cost difference is due to the fact that larger drainage structure projects are let to contract, and minor work is performed in-house.

Drainage Pipe Installation

The $39.13/LF unit cost of installing drainage pipe with in-house forces was slightly higher that the $31.08/LF contracted cost. This may be due to the fact that in-house work constitutes projects of lesser magnitude.

Tree Trimming

The majority tree trimming and tree removal is let to contract. These contracts are usually combined with mowing contracts and were priced per mile. The discrepancy between in-house and contracted unit costs are most likely due to the fact that more labor intensive work, involving hand trimming from a bucket truck, is let to contract. All tree removal contracts provided by procurement were fixed price lump sum contracts. Tree removal involves an extreme amount of variability from job to job, which is reflected through contract prices.

Mowing

Almost all-interstate mowing is outsourced by SCDOT. The agency no longer has the necessary equipment, and personnel to adequately perform this activity. Contractors bid for this work by acre and per cycle. A typical contract consists of five cycles per year. As indicated in Table 1, it appears that outsourced and in-house performed unit mowing costs are about the same.

Chip Sealing

One way to preserve many of the secondary roads is through the use of chip sealing. Most contracts have many activities added to them such as pavement striping, raised pavement markers, and full depth patching. Only the cost associated with a single chip sealing treatment has been compiled. After reviewing many chip sealing contracts, it appears to be more expensive to outsource this activity. As noted in Table 1, the in house unit cost was \$0.31/SY, the outsourced cost was \$0.77/SY. Fiscal Year 04-05 data, not shown in Table 1, indicates the in-house cost had increased to \$0.50/SY.

Guardrail Installation

In general, SCDOT does not have the necessary equipment to perform guardrail installations and it is acknowledged by SCDOT personnel that contractors may perform better quality work. The difference in unit cost shown in Table 1 is most likely due to minor projects being performed in-house, with major projects let to contract.

Pavement Striping

SCDOT performs much of the pavement striping, however they also use contractors to supplement their efforts. The cost to perform this activity with in-house forces is approximately \$0.19/LF as compared to outsourcing this activity at \$0.03/LF (painting, not thermoplastic marking). The reason for the cost differential is the fact that in-house work is typically small symbol marking projects, whereas major projects of significant distance are almost always let to contract.

Raised Pavement Marker Installation

As noted in Table 1, the cost for SCDOT installation of raised pavement markers is \$17.28 each, whereas contracted costs are \$2.61 each. SCDOT seldom performs initial marker placement, performing instead marker replacement. SCDOT probably performs less than 5000 marker replacements per year.

Sign Replacement

Limited data were available to compare sign replacement costs. One recently received contractor bid for a project involving approximately 7000 sign replacements stipulated \$35.31 per sign with SCDOT providing the signs. In-house unit costs, excluding material, averaged \$25.28 in FY 03-04, and (not shown in Table 1) \$26.57 in FY 04-05.

Full Depth Patching

A significant amount of full depth patching is outsourced. Contracts, which were used for comparison, were for full depth patching assuming a 6-in. uniform depth. Many contracts included a separate asphalt pay item for leveling of the roadway after the full-depth patch was complete. This was considered to be a separate activity and therefore this cost was excluded from the contract analysis. The traffic control cost, and mobilization cost was also divided between the two activities. As noted in Table 1, the cost to perform this activity with in-house forces in FY 03-04 was $25.12/SY. After reviewing 28 FY 03-04 contracts, it was determined that the average outsourcing unit cost was $33.25/LF. It appears to be more cost effective to perform this activity with in-house forces, but the cost difference may be due to the fact that contractors were using more expensive fill material.

Bridge Replacement

SCDOT has been mandated to outsource the construction of bridges over 120 ft in length, which has made a cost comparison difficult. The unit cost of longer bridges are most likely less than the unit cost of the shorter bridges that are replaced with SCDOT forces.

Maintenance Activities for Which a Cost Comparison Could Not Be Made

Whereas reasonable cost comparisons could be made for many of the activities listed in Table 1, a meaningful cost comparison for other activities could not be executed. This is primarily due to the fact that many activities are performed exclusively in-house, or exclusively let to contract. And, in some cases (as also noted with activities listed in Table 1), the magnitude or type of activity that is outsourced is vastly different from what is performed in-house. The activities for which a cost comparison could not be made are listed in Table 2. Cable rail installation is exclusively let to contract. Herbicide treatment applications are often included in mowing contracts but this activity is not a contract pay item. Rest area maintenance is completely outsourced and there is no desire within SCDOT to perform this activity in-house. Crack sealing is performed both in-house and under contract, but in-house work is currently recorded in units of lane miles, whereas the contract pay item is pounds of sealant. Right-of-way fencing is performed in-house only for minor repairs whereas major new fence installations of extensive

TABLE 2 SCDOT Maintenance Activities That Could Not Be Compared

Maintenance Activity	Reason
Cable rail installation	Completely outsourced
Herbicide treatment	Insufficient data
Rest area maintenance	Completely outsourced
Crack sealing	Incompatible units of measure
Install ROW fence	Insufficient data
Litter pickup	Not let to private contract
Snow/ice removal	Hourly wage rate stand-by contracts only
Vehicle/equipment maintenance	Performed entirely in-house
Features inventory	Insufficient data

fence quantity are let to contract. Litter pickup consists of voluntary assistance programs such as Adopt-A-Highway, and in some districts, corrections inmates perform the activity. Snow and ice removal is contracted only on a cost reimbursable hourly basis with no units of measure recorded. Routine vehicle and equipment maintenance is performed in-house with major repairs let to contract. SCDOT personnel anticipate contracting a number of features inventory tasks in the future. At present only one contract for a guard rail inventory has been let to contract.

DECISION FACTORS EXPLORED IN SEVEN DISTRICT WORKSHOP SESSIONS

As noted in the literature, many states have had difficulty projecting the cost savings benefits associated with the outsourcing of maintenance activities before initiating such a project. Indeed, as noted in the previous section of this paper, even a comprehensive analysis of all cost data for an entire fiscal year, may not produce useful comparisons of in-house performed vs. outsourced costs for all anticipated outsourcing activities. Political and administrative mandates to outsource maintenance services have not always produced anticipated benefits. Thus the state agency considering maintenance outsourcing should carefully examine other factors impacting the two alternatives. These factors, termed “decision factors” in this paper, include agency and contractor equipment availability and expertise, workloads, equipment utilization rates and internal policies, the ability to respond to emergency situations, contract administration costs and resources, demands of seasonal work, and the ability of local contractors to provide specification conforming work.

In order to formally explore these decision factors within the SCDOT, a series of seven half-day duration workshops were conducted, one in each SCDOT district office. At least ten or more SCDOT maintenance professionals attended each workshop, thus the entire effort produced a compilation of input from over 70 highway maintenance professionals. Prior to each workshop date a meeting agenda was distributed listing the twenty maintenance categories for which SCDOT had some experience, or interest in outsourcing. Workshop participants were informed that the reports compiled by the Clemson University researchers would not identify the district by name. Notes were taken during the workshops and a draft of the notes was forwarded to the participants after the workshops for their additions and corrections. Selected excerpts from the final published workshop notes appear as Tables 3 through 7 of this paper. To maintain confidentiality of the workshop proceedings, the districts are not identified by their actual numerical designations in the tables.

As noted in Table 3, the decision to outsource drainage-related activity depends on project magnitude. There is a need to address the adequacy of contract specifications as more drainage work is let to contract. From the workshop input obtained with respect to mowing shown in Table 4, it can be concluded that mowing is an appropriate activity for outsourcing in that it places high seasonal demands on SCDOT forces. And again, some improvements in contract specifications are needed to more specifically define the contractor’s obligations. As noted in Table 5, it appears that major painting and thermoplastic marking projects are

TABLE 3 SCDOT Workshop Input: Outsourcing Drainage

District	Workshop Input
A	Outsourcing decision is dictated by project magnitude.
B	Majority of work is performed in-house. It is better to outsource activities other than those related to drainage maintenance that are less “public sensitive.” Drainage structure repair, curb and gutter repair, and cross line repair are good outsourcing candidates.
C	Most drainage related activities are performed in-house. Catch basin repairs and conversions have been let to contract. Better and more uniform specifications are needed.
D	Catch basin repair is a good candidate for outsourcing. The increased need for environmental compliance is making drainage activities more costly.
E	Large diameter pipe replacement, and catch basin repair, and shotcrete pipe repairs are outsourced. Contractors for this work are available, however catch basin repair bids are somewhat high.
F	A pressing need in this district is to widen roads to a 24 foot paved shoulders and adequate earth bank shoulders. This work would be a good candidate for outsourcing contracts. Catch basin repair and updating could also be outsourced.
G	Most drainage work is performed with in-house forces. The district plans to let some basin conversions to contract in the near future. One county has let a ditch cleaning contract. Some cities perform sweeping related activities under contract.

TABLE 4 SCDOT Workshop Input: Outsourcing Mowing

District	Workshop Input
A	Larger counties prefer contracting, smaller counties do not. Workload dictates significant outsourcing.
B	All mowing work is let to contract. Enforcing contract provisions has been a problem. There are a significant number of available contractors to bid the work.
C	In general all mowing has been satisfactorily performed under contract. An improved “final cleanup” specification is being draftee. Mowing contractors have damaged electrical equipment and posts.
D	District prefers to continue contracting interstate mowing although some contract problems have been encountered. The district would prefer to perform other mowing in-house because they do a better job. In-house is 50% less costly.
E	Only interstate mowing is contracted as per state wide mandate. Routine mowing was at one time contracted but contractor performance was poor. The district has adequate equipment for routine mowing.
F	Approximately 95% of mowing in the district is contracted. Mowing is labor intensive, and contracts free up personnel to perform other tasks. Mowing contracts need to be written to clearly specify the obligations of the contractor and the pay item.
G	The district is attempting to contract all mowing activities. Boom mowing (back slopes and ditches – year end cleanup) is performed in-house but the necessary equipment is limited. There are political pressures to mow some areas more often than planned. Contractor compensation on the basis of acres generates disputes.

TABLE 5 SCDOT Workshop Input: Outsourcing Markings and Painting

District	Workshop Input
A	The district is moving toward more outsourcing of thermoplastic work. Raised pavement marking contracts need to be let earlier to maximize use before ice and snow operations may be required.
B	Most work is contracted and should remain so. A district-wide on-call contract would be appropriate. The district no longer has the equipment to perform centerline painting.
C	All pavement marking activities except symbol markings are let to contract. Centerline painting has been let to contract with good results
D	Thermoplastic markings are let to contract. Raised pavement marking has been contracted at a cost of about $400 per mile.
E	Edge and centerline markings are contracted though the Construction Office. Roadway painting needs to be retained in-house for quick response time. Raised markers are contracted because it is labor intensive.
F	All centerline markings are contracted. Some “by hand per cut” markings are best performed in-house to respond to critical needs. Some centerline painting is contracted but the district also has an excellent paint crew serving some counties. Raised markings are contracted.
G	Thermoplastic marking activities are let to contract. Most symbol markings are placed in-house. It would be preferred to let symbol markings to contract if the current contracts are properly executed.

appropriate for outsourcing, whereas minor painting and symbol marking projects are best performed in-house. As noted in Table 6, full depth patching is an appropriate activity for outsourcing, but as more work is let to contract, there may be an increasing need for additional inspector training. As shown in Table 7, some districts have well trained and equipped bridge replacement crews, and those district personnel would prefer to retain those crews. There was some concern that certified crane operators would be leaving SCDOT for more lucrative employment in the private sector, thus impacting the district’s ability to outsource this activity.

Additional suggestions obtained from the workshops included initiating a formal maintenance contractor prequalification system and modifications to current contracting procedures including the use of incentives and progress payment retainage. Workshop participants were generally able to justify their preferences as to whether or not a given activity was appropriate for outsourcing. The factors that impact outsourcing in one district or county may or may not prevail elsewhere. It therefore appears that mandates suggesting or dictating outsourcing of some activities statewide would not be in the best interest of SCDOT or the public.

CONCLUSIONS

As part of a recently complete research project conducted by Clemson University for the South Carolina Department of Transportation, the relative merits of outsourcing highway maintenance activities as opposed to performing those activities with in-house forces, were examined. A review of data contained in SCDOT maintenance management cost reporting system and all contracts let for FY 03-04 were examined. This review determined that activities such as drain pipe installation, mowing, sign installation, and full depth patching could be outsourced at approximately the same unit cost as in-house performance.

TABLE 6 SCDOT Workshop Input: Outsourcing Full Depth Patching

District	Workshop Input
A	A substantial amount of work is performed by contract. Inspectors need training in order to be able to better evaluate conforming work.
B	Full depth patching should continue to be outsourced. However, better performance specifications are needed in the contracts.
C	Most work is let to contract with good results. More full depth patching is needed throughout the district.
D	Approximately 95% of work is contracted. There have been no problems with specifications or work quality.
E	Some work has been performed in-house, some by contract. This activity may become more important if chip sealing is not resumed. Contractors capable of performing chip sealing are not capable of performing full depth patching.
F	Since initiating mowing contracts, crews formerly performing the mowing function can not address patching. Approximately 60% is performed in-house. Outside contractors perform well but occasionally do not extract poor sub-grade material.
G	This work is performed by both in-house and by contract. There are no strong feelings as to which is preferred. Work quality is perhaps better when performed in-house.

TABLE 7 SCDOT Workshop Input: Outsourcing Bridge Replacement

District	Workshop Input
A	District crews are effective in performing bridge replacement. District forces can perform this activity more quickly and at less cost.
B	Maintenance bridges can be replaced with district forces but sufficient equipment is not available. Most bridge maintenance is performed in-house. Wage rates for crane operators need to be increase.
C	One districtwide replacement crew has functioned very effectively. There is a long time period to get replacement contracts executed
D	District can erect bridges up to 120 ft in length. About six to eight are erected per year. When contracted, it takes 2 to 3 years. In-house and contract costs are comparable.
E	Most bridge work is let to contract which is the preference. There is a districtwide bridge crew that has proven to be very effective, mostly addressing problems related to rotting timber piles.
F	There are now two districtwide crews performing bridge replacement. Contractor availability may impact the cost of performing additional work in the future. Crane operators must be paid a competitive wage
G	Two districtwide bridge replacement crews perform effectively. The district would prefer to retain this capability. Bridge maintenance is performed in-house. There may not be sufficient number of locally qualified contractors to perform bridge maintenance, thus contracts would not be cost effective.

It was difficult to compare unit costs for such activities as drainage structure installation, tree trimming, guard rail installation, raised pavement marker installation, and bridge replacement because of differences in project magnitude, complexity, or labor intensity. A comparison could not be made for other activities such as rest area maintenance and cable rail maintenance because these activities were exclusively let to contract in FY 2003–2004. For one activity, crack sealing, the unit of contract measure utilized in the maintenance management system was not the same as the contract pay item.

Workshops conducted in the seven SCDOT districts provided additional insights with respect to the relative merits of outsourcing vs. in-house execution of highway maintenance activities. In general, the maintenance professionals attending the workshops could provide firm justifications for their preferences as to whether or not a given activity should be outsourced in their districts. Labor intensive activities such as mowing and complex activities such as major drainage structure installations were cited as good outsourcing candidates. Constraints such as equipment availability, local contractor expertise, SCDOT inspection and administration resources, and immediate SCDOT response time were cited among their important decision factors. The workshop participants also provided good suggestions for revising outsourcing contracts to improve their ability to obtain quality work. This workshop approach to soliciting the field perspectives of maintenance professionals is recommended to other state transportation agencies that are considering alternative maintenance outsourcing strategies or policies.

REFERENCES

1. Ribreau, N. *Synopsis of WSDOT's Review of Highway Maintenance Outsourcing Experience*. Proc., Transportation Research Board Committee on Maintenance and Operations Management Annual Conference, Washington, D.C., January 2004.
2. *Oppaga Progress Report: Department of Transportation Expedites Privatization*. Office of Program Policy Analysis, Florida Legislature, April 2003.
3. Witheford, D. K. *NCHRP Synthesis 246: Outsourcing of State Highway Facilities and Services*. Transportation Research Board, National Research Council, Washington, D.C., 1997.
4. Cambridge Systematics, Inc. *Transportation Asset Management Guide*. NCHRP Project 20-24(11), Final Report, prepared for the National Cooperative Highway Research Program, Washington, D.C., November 2002.

PART 1: OUTSOURCING MAINTENANCE ACTIVITIES

Evolution of Highway Maintenance Outsourcing in Alberta, Canada

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In 1995, Alberta Transportation and Utilities took its first steps of many to outsource the highway maintenance work. This work covered all summer and winter maintenance of the provincial highway network. The department overcame many challenges as it changed its role from delivering the service to managing the delivery of the service by the private sector.

From day one, the industry and the department began to work together on forming a relationship of understanding from each others point of view. This relationship was referred to as "partnering" and it would prove to be beneficial for day to day operations and in the future contracts.

Following the outsourcing and prior to the next round of tendering, the department along with the industry conducted a major reengineering of the existing maintenance process. The group undertook a thorough review of all the maintenance specifications and contract requirements in an effort to identify the risk and allocate it where it could be best managed. During this period the department also sold its maintenance shops and increased its responsibility by assuming approximately 15,000 km of secondary highways from local municipalities.

All of these changes were incorporated into the contracts prior to the second round of retendering. As result of these changes there were significant savings. The department is now about to embark on its third round of retendering. Maintaining a level playing field for all contractors, creating a competitive bidding atmosphere, dealing with increased public expectation and issues on environment and insurance are just a few of the items that were reviewed in this round.

HIGHWAY MAINTENANCE OUTSOURCING: THE BEGINNING

In the early 1990s, the Alberta government, like many other governments, was faced with the growing pressure of increased deficits and debt. Change was required in order to bring both under control and in 1993 the government put forward a new mandate. The delivery of government services through the private sector was to be considered where it was cost effective and provided good service to the public. As part of the Alberta government's mandate, Alberta Transportation and Utilities (AT&U) decided to outsource the maintenance of the 15,500 km of primary highways within the province.

Outsourcing of highway maintenance activities was not new to AT&U. Prior to 1995 the department had already outsourced maintenance activities such as line painting, mowing, crack filling, and some snowplowing. However, this piecemeal approach to outsourcing was not efficient and did not necessarily meet the department's goal to deliver services by the best and most cost-effective means.

The department was also faced with an aging equipment fleet that was not being fully utilized at all times of the year. A good portion of the snow plow fleet sat idle during the summer months because of the nature of the maintenance work done by the department. Capital costs to replace the fleet were significant and given the financial situation of the province at the time this was not an option.

In addition, the public expected the department to provide the same level of maintenance service or higher. This was quite the task considering the department was facing budget cuts from one side and increased costs and expectations from the other. As a result the department began looking for a new approach to deliver highway maintenance services through the most cost-effective means.

To achieve this goal, AT&U decided to increase its outsourcing activities to include all highway maintenance and routine bridge maintenance services. The department's role was to change from one of doing the work to one of steering the work by setting policy and standards and monitoring and ensuring that the performance standards were met.

AT&U's objective was to increase efficiency in its outsourcing programs and it planned to do this by using a competitive bid process, managing standards, monitoring performance, reducing government administration, providing opportunities for innovation and facilitating economic growth in the private sector. Ensuring public safety, preserving the public's investment in transportation infrastructure and contributing to the Alberta Advantage were the department's main goals and managing these became the focus.

DEVELOPMENT OF MAINTENANCE CONTRACTS

In the spring of 1995, the minister of AT&U was presented with an alternative for highway maintenance that included geographically based mixture of unit and lump sum prices and all-encompassing contracts. The proposal received support from the minister and the department was given the green light to proceed with the development of a more detailed model.

Work soon began on what was to be known as the Alberta model for outsourcing highway maintenance. Department staff, contracting industry, other stakeholders, and a consultant developed a set of guiding principles:

- Improve the cost effectiveness of the delivery of maintenance throughout the province;
- Maintain and manage the current level of service (LOS);
- Pay contractors fairly for work done to department standards;
- Establish a shared risk environment between the contractor and the department;
- Ensure existing department staff were treated fairly and minimize any negative impact on them; and
- Eliminate any potential adverse impact on the road users during the change-over period or subsequent contract period.

The department wanted to learn about the successes and mistakes of others who had ventured down the same path. It conducted a thorough review of background documents, technical papers, specifications, best practices, and contract documents from the United Kingdom, Australia, New Zealand, British Columbia, and some U.S. states. This research assisted the department in deciding on the framework that would become the Alberta model:

- Long-term contracts (5 years) with a provision for price adjustments due to inflation–deflation in contracts to provide contractors with an opportunity to receive a return on investment;
- Thirty geographically based contract maintenance areas (CMAs) that cover an average of 500 two-lane equivalent kilometers per CMA and included all routine roadway and bridge work but not extensive payment overlays or repairs to bridge structures;
- A maximum of four CMAs allowed per contractor to prevent monopolies;
- A combination of unit priced and lump sum contracts that allowed the department to control the LOS provided—contractors paid according to the rates set for work that they preformed plus a lump sum to cover defined routine highway maintenance work and fixed costs;
- Specifications—end product specifications where practical;
- The department would issue work orders to contractors for specific activities;
- Quality assurance inspections through field-level maintenance contract inspectors; and
- Industry consultation—exchange of information and development of a partnership relation.

The outsourcing project used task teams to complete specific components of the request for proposal (RFP) development. Each team consisted of department personnel from managers to field personnel that were familiar with highway operations. Contractor staff and other stakeholders also participated on the teams. Task teams were encouraged to develop the best solution for Alberta, using their practical understanding of the factors that would impact the specific task. Content of specifications were developed by task teams and then handed over to technical specification writers. Field operations staff collected the data required for the generic specification and the unit price schedule. Task teams were given a short time frame to build solutions that would work for Alberta.

In August and early September 1995 technical specifications were finalized for primary highway maintenance activities. This was a significant accomplishment for no such specifications existed within the department. The department wanted to ensure the existing LOS was maintained which meant using mostly method-based specifications, as the contracting industry did not have any experience performing this type of work. This approach shared the risk between the department and the contractor and allowed the contractors to work closely with department staff to transfer the required knowledge.

INDUSTRY INVOLVEMENT

Throughout the contract development, the industry was asked to provide participants to work on committees in the development of specifications, selection and review process, and insurance and bonding considerations. The industry was also kept informed through the consultation:

- Half-day briefing sessions for all interested parties at various locations across the province;
- Detailed 2-day seminars on contract maintenance held at several locations; and
- A single 5-day seminar on the details of how all maintenance activities were preformed in the province of Alberta.

It was important that the existing contracting industry understood the format of the Alberta's outsourcing model for they would soon be assuming the responsibility for the maintenance on a complex and diverse highway system.

STAFFING PRIOR TO OUTSOURCING

In addition to informing the contractors as to what to expect with the outsourcing, the department had to also inform its staff. Under the Alberta model of outsourcing, all highway maintenance work would be completed by the maintenance contractors. Employees directly involved in completing these activities were informed in advance that their employment with the department would be terminated as a result of the outsourcing process. The department offered severance packages and provided training and job search assistance for all affected employees.

There was no requirement within the RFP process that the contractors had to employ any former employees of AT&U. However, the RFP did specify the type of experience that was required and this was assessed. The former AT&U employees had these skills and as a result about 80% were hired by the successful contractors. Of those not hired, the majority of them had decided to retire or look for other lines of employment.

Prior to outsourcing, the department employed about 650 people directly in highway maintenance. When the outsourcing was complete in December 1996, the department employed 80 people in highway maintenance. The staff that remained focused their attention on managing and not delivery of the highway maintenance service which was now the responsibility of the maintenance contractor.

EQUIPMENT AND FACILITIES

AT&U had a considerable investment in equipment and facilities prior to outsourcing. All of the equipment—including snow plows, line painting trucks, and pickups—were made available to the private sector at fair market value. Details regarding the unit price of each piece of equipment were provided in an information package that was distributed to prospective contractors. The majority of the equipment was sold to the contractors and all unsold equipment was put up for auction.

Existing maintenance facilities, which were owned by another government department, were offered on a lease basis to the contractors at market value. During the tendering period, prospective contractors were permitted to inspect the maintenance yards and equipment. At the end of the tendering period several of the maintenance facilities were declared surplus

FIRST ROUND OF RFPs

Once the decision was made to outsource the highway maintenance program in Alberta, a number of tasks needed to be completed before the first set of contracts could be awarded. One of the most significant tasks was the development of a well-defined RFP process. It was important to have a process that clearly identified the department's expectations and it was equally important to the contractors to know how the department was going to evaluate and score each proposal.

RFP DETAILS

The department prepared RFP documents for each CMA. Each document followed the same format and consisted of nine major sections:

- RFPs which contained definitions, contract, and proposal evaluation criteria;
- Instructions to bidders which identified how the proposals were to be structured and what forms were required;
- Special provisions which contained additions, deletions, or modifications to the specifications that were specific to the CMA;
- Unit price schedule which contained provisional annual quantities of work;
- Plans—boundaries of CMA and location of current facilities and AT&U material stockpile sites;
- List of employees;
- List of current and surplus equipment;
- List of facilities; and
- Local features—unique areas that require special maintenance attention.

In addition to the RFP, the following documents also formed part of the contract. The first document was the general specifications, which contained the terms and requirements of the contractual relationship between the department and the contractor. The second document was the technical specifications which addressed the technical requirements and payment terms for all bid items in the contract. The last document was the technical drawings which related to the technical specifications. These documents were the same for all RFPs.

PROPOSAL EVALUATION

The department analyzed the proposals through a four-envelope system. The criteria used to assess the content of each envelope and relative weightings were as follows.

- **Envelope 1** contained the technical and mandatory requirements including bonding and insurance. If a proposal did not meet all the requirements of Envelope 1 it was to be rejected and the remaining bid documentation was returned to the bidder unopened. All contractors who submitted proposals in the first round met the requirements.
- **Envelope 2** contained the work execution plan. Information contained in Envelope 2 allowed the department to evaluate the contractors' ability to carry out the maintenance work required for the duration of the contract. Each contractor was to submit a work plan that included information on management skills, supervisory skills and experience, crew skills, response to emergencies, adequacy of facilities, equipment and technology, an environmental plan, work strategy and quality assurance. A team of department employees assessed the contents of

Envelope 2 and scored each component using a score of 1 to 5 with 5 being excellent. The work plan was worth 40% of the overall proposal score.

- **Envelope 3** contained information on pricing and the quantities of work. Each proposal was assessed for the sensitivity of prices due to fluctuations in the quantities of the work throughout the duration of the contract. The team that evaluated the pricing was different from the team that evaluated Envelope 2. Neither team discussed with one another the proposals details during the evaluation period. Envelope 3 was worth 60% of the overall proposal score. Fixed-cost component of contract could not exceed 45% of the overall value for the contract.
- **Envelope 4** contained financial information on the contractor to verify the firm's financial viability. Only the successful contractor's Envelope 4 was checked. All checks were done by an independent consultant.

TENDER TIMELINES AND RESULTS

The 30 CMAs were tendered and evaluated over a period of a year. Contractors were only permitted to have up to a maximum of four CMAs awarded to them. The first set of RFPs containing seven CMAs were released in September 1995. Over the next 9 months the remaining 23 CMAs were tendered in packages of three and four CMAs every 6 to 7 weeks. The last contract was awarded in October 1996. At the completion of the RFP process the department had entered into contracts with eight contractors for the maintenance of the provincial highway system.

The true financial impact of highway maintenance outsourcing was not fully felt until FY 1997–1998 which was the first year the entire maintenance operations program was contracted out. According to the 1997 KPMG Management Consulting report "Outsourcing of the Highway Maintenance of Provincial Highways—Financial and Other Impacts" the outsourcing highway maintenance had created a conservative cost savings for the department in indirect overhead costs of $3 million dollars or 3% annually. Other provincial departments such as Alberta Treasury and Municipal Affairs also benefited from the outsourcing initiative and incurred costs savings of $4.5 million over the same period.

FIRST 5 YEARS OF MAINTENANCE OUTSOURCING

On January 16, 1996, the first set of contracts took effect and in most cases, the transition was seamless. At 4:30 p.m. on a Tuesday, the operator who was driving a snow plow truck for AT&U simply switched ball caps and at 4:31 p.m. the same day started working for the maintenance contractor. For the first few months it took employees on both sides some time to get used to their new roles. Biweekly meetings were held on an ongoing basis between the contractor and the department to resolve any issues that came up. Lines of authority and communication were established between department and contractor staff as the relationship developed between the two parties.

From the start of the contracts, it was the department's intent to encourage the foundation of a cohesive relationship between the contractor, its principle subcontractors, suppliers, and the department. The working relationship was to be structured to draw on the strengths of each organization to identify and achieve common goals. This working relationship was to be referred to as “partnering” and participation was totally voluntary. All contractors were in favor of entering into a partnering agreement with the department. This agreement did not change the legal relationship of the parties to the contract nor did it relieve either party from any of the terms of the contract.

Over the years, the partnering concept with the maintenance contractors began to flourish. Maintenance contractors participated in almost all department working groups regarding maintenance and roadway operations. The partnering process led to improved and effective communication and innovative solutions for common issues. The development of contract performance measures, the contract administration manual, and the electronic data transfer were a just a few of the major items the groups achieved through partnering.

EXTENSION OF CONTRACTS

Two years after the last maintenance contract was awarded, the department began to consider how it was going to retender the next round. A considerable amount of time and effort was going to be required to put together all 30 RFPs in the same year therefore a decision was made to consider extensions.

The department provided each maintenance contractor the opportunity to extend their maintenance contract by 1 to 3 years. Each contractor was requested to put forward a proposal and the department evaluated each one of them for best value based upon the criteria specified in the RFPs. In the end, two contractors received a 3-year extension, two contractors received a 2-year extension, and the remaining five contracts would be tendered as they expired. Because of the extension, the contracts were now staggered and the retendering was more manageable.

REENGINEERING OF MAINTENANCE CONTRACTS

Immediately following the extensions, between the period of November 1998 and June 2000 the department along with the industry undertook an extensive review of the entire maintenance process. The objectives were to

- Develop equitable risk sharing plans between the department and the contractor that promoted efficiency and maintained the LOS;
- Develop a profitable and sustainable maintenance contracting industry within Alberta;
- Develop a strong private-sector confidence in the Alberta maintenance partnering system;
- Encourage innovation in the maintenance contract industry;
- Reduce contract administration costs by simplifying the payment structure; and
- Reduce public capital invested in highway maintenance by selling off the highway maintenance facilities which were owned by the department and leased to the maintenance contractors.

A team of department staff and senior members of the Alberta Roadbuilders and Heavy Construction Association conducted an initial review of the maintenance contracts. Terms of reference and guiding principles were then developed. They included the following:

- Increase risk sharing with the contractor and predictability of contract costs for the department;
- Identify risks and improve the allocation of those risks so that they are handled by the partner which is best able to manage them;
- Increase contractor flexibility in meeting contract requirements without compromising quality and safety standards set by the department;
- Simplify the general contract specifications with regards to data requirements for payment under the contract;
- Develop service levels for all maintenance work for primary and secondary highways; and
- Develop the RFP documents that clearly specify the criteria to be used to evaluate each proposal and select the successful contractor.

A number of task groups consisting of members from the department, maintenance and road contractors, insurance and bonding industries, municipality, and other public- and private-sector groups were established to carry out the work. Within the task groups, contractors assumed equal roles in developing and achieving the group's objectives and work plans. Senior management leadership provided support to all parties involved and ensured the groups remained focused on their goals. The task groups reviewed best practices and processes across North America and developed new specification approaches to meet the objectives in Alberta. Two key areas—winter maintenance and winter service delivery—received significant attention.

In Alberta winter maintenance is a significant item within the highway maintenance contracts. The unpredictable weather can have a profound effect on the overall value of work. Instead of using a lump sum method to pay for winter maintenance, the department maintained its unit price system for payment of maintenance work. Contractors were paid by the hour for each hour they worked and paid for the material they used. To promote responsible management of material and to transfer some of the risk to the contractor, new sliding scale payments were introduced for snow plow hours and salt usage.

Another significant item that required a lot of attention was the winter service delivery. In the first round of contracts the department indicated to each contractor the number of snow plows trucks that were required and where they were to be stationed. With the decision to sell the maintenance facilities this all changed. Maintenance contractors would now be responsible for identifying the numbers of snow plow units and the location of the maintenance facility. This promoted the development of a winter LOS specification which encouraged contractors to be innovative in identifying the most economic mix of facilities and equipment. It also promoted the sharing of resources and facilities with other roadway jurisdictions. The specification was truly a "Made in Alberta" solution, as no specification of this kind existed inside or outside of Canada.

While the reengineering was taking place, a Premier's Task Group was looking at the issue of highway disentanglement with municipalities. Some of the issues that promoted this review included the inefficiencies in several agencies responsible for carrying out this work and the financial inability of the municipalities to carry out this work in the future. As a result of the disentanglement process the Premier's Task Group recommended that the province takes over

100% responsibility of the secondary highway system, including major highways through key cities. This effectively doubled the highway network that the department was responsible for maintaining and this had a significant impact on the second round of retendering.

CONTRACT SIZE AND DURATION

Prior to the second round, the department had some concerns with the level of competition amongst the existing contractors when it came to bidding. In an effort to address this concern, the department agreed to allow the contractors to bid up to a total of seven CMAs. With the addition of the secondary highways this effectively changed the maximum contract size from about 2,000 to 7,000 km. This was a 2½ times increase in scope of work from the initial contracts.

The department also reviewed the length of the current contracts. However, no changes were made for it was felt that 5 years was long enough for a contractor to depreciate their equipment and facilities on this initial capital investment. The department retained the option to extend a contract if it felt that was in the best interest of the taxpayers.

The estimated contract value for a CMA ranged from \$4 to \$6 million on an annual basis. A contract consisting of seven CMAs was worth approximately \$42 million on an annual basis and \$210 million over the term of the 5-year contract. This in itself prompted a lot of interest from the contractors.

OUTCOMES OF SECOND ROUND OF RETENDERING

The department retendered 17 out of the 30 CMAs in 2000 and the results exceeded the department's expectations. Unit prices fell approximately 28%. Table 1 is a summary of the financial results of the maintenance tendering for the 17 CMAs, which were identified in the KMPG (management consultant) report which was prepared for the department in June 2001.

In addition, \$45 million was also raised from the sale of the maintenance facilities previously owned by the government. As well, the Alberta government saved approximately \$800,000 in grants that were paid out annually to the municipalities, in lieu of taxes for the maintenance facilities.

Over the course of the next few years, the specifications were slightly modified and stricter environmental requirements for maintenance shops and requirements for working around

TABLE 1 Summary of the Financial Results of the Maintenance Tendering for the 17 CMAs

Outcome Measure	Result
New contracts (year 2000)	\$3,705/km
Old contracts (prior to year 2000)	\$5,117/km
Reduction in cost/km (%)	28%
Reduction in cost/km (\$)	\$1,412/km
Total annual cost reduction	\$26,419,932

TABLE 2 Second Round of Retendering

Outcome Measure	Result
Old contracts expiring 2003 (five CMAs North Central Region)	$28,644,645
New contracts 2003 (five CMAs)	$24,865,384
Old contracts expiring 2004 (four CMAs Peace Region)	$23,294,582
New contracts 2004 (four CMAs Peace Region)	$18,957,513

waterways were introduced into the contract. Despite the changes the department continued to see similar savings for the remaining 13 CMAs that under went their second round of retendering (Table 2).

THIRD ROUND OF RETENDERING

The department is currently in the process of retendering 19 of the 30 CMAs. Out of the 19 CMAs it will be the third round of retendering for 15 of them. A number of new requirements have been added to the contract and these include:

- Increased emphasis placed on environmental management of maintenance yards. All maintenance sites will require an environmental management plan and as a minimum covered storage for all salt and mixed sand–salt piles;
- Additional spare operators for snow plows;
- Increased traffic control on high-volume roads;
- Increased number of pre-wetting units and wings on snow plow units; and
- Use of new technologies involving remote weather information systems and automated vehicle location systems.

In keeping with the department's practice of involving the stakeholders in the decision-making process, the first step was to consult with the industry on the contracting process. This step proved to be very beneficial in the last round of retendering. The issues discussed included the contract size and duration, specification changes, retendering award process, and retendering schedule.

As in the previous round, maintaining a level of competition amongst the contractors is a key element in receiving good value for the contracts. In the second round, contractors were allowed to hold up to a maximum of seven CMAs. For the third round, the department is permitting the contractors to hold up to a maximum of nine CMAs, encouraging existing contractors to bid on their competitor's area. The downside to this is there is a potential that the number of maintenance contractors in Alberta may be reduced thus decreasing competition for the forth round. However, the department is well aware of this risk and is willing to accept this and make the appropriate changes to ensure that competition exists.

To evaluate the proper length of contracts which allows the contractors a longer depreciation period for equipment and facilities, the department is offering contracts that range in length from 5 to 7 years. The first set of seven CMAs retendered will be for 5 years, the next set of seven CMAs will be for 6 years and the last set of five CMAs will be for 7 years. This set up will also help stagger the CMAs in future retendering so that not all the contracts expire in the same year. A lot of time and effort is put in by the contractors and the department when CMAs come up for retender and this set up will help reduce this workload. Another benefit to staggered contracts is that if an existing contractor loses out on his area, then he will not have to wait a full 5 years to get an opportunity to bid on another area.

The department and the industry as in past years also did a complete review of the current specifications and made some minor changes to items that were causing concerns. The review process lasted for about a month and a number of specifications were revised. In addition to the specifications, the department decided to change the evaluating process of the RFP. A decision was made to move away from a point award system for specific requirements to a pass–fail system. Under the new system, a contractor would be required to meet all the minimum requirements before any consideration is given to awarding the contract. This approach clearly laid out the department's requirements and contractors are required to meet or exceed them.

The last item the department reviewed was the retendering schedule. Some of the smaller contractors that wanted to get into the business had indicated to the department that it was very difficult to bid on a large number of CMAs at one time. It required considerable resources to bid and a tremendous amount of capital. In response to this issue, the department decided to release the RFPs at different times over the period of a year. The RFPs would be released in groups of three to five CMAs approximately every 11 weeks.

In another effort to provide the smaller contractors an opportunity to get into the maintenance industry, the department decided to continue with its orphan CMA award rule that was introduced in the RFPs in 2001. Generally, the department gives preference to combination bids for ease and cost of administration. However, if there are less then three proposals that contain all CMAs and each proposal exceeds the department's estimate by more than 5%, then the department would consider awarding individual CMAs.

CURRENT STATUS

The department started 2005 off with the release of the RFPs for the four CMAs in the Lethbridge District. As expected, unit prices decreased, for this was only the second time the area was competitively bid. The other 15 CMAs were up for rebid for the third time. RFPs for 10 of the remaining 15 CMAs have closed and unit prices have not increased substantially. The unit prices for most of the activities have only increased with inflation since the last time the CMAs were bid. There were also increases in the fixed costs but that was expected with the new requirements for sand–salt storage structures and the additional manpower for the winter months.

To date there has been considerable interest in the RFPs from contractors both inside and outside of the province. For each set of CMAs released the department has received three or more proposals. The interest has resulted in competitive proposals being submitted. On two of the occasions the difference between the successful proposal and the second place proposal was less than 2%.

SUMMARY

It has now been about 10 years since the department outsourced highway maintenance. Over these years, the department along with its stakeholders has made a number of changes to the Alberta model. Risk is identified and allocated to the partner that can best manage it and the LOS provided is controlled by the department. Listening to the needs of its stakeholders has always been a major component of the department's business. As a result, private-sector confidence in the Alberta system is very high and costs are low.

When the department outsourced this work, many of the department's staff was asked to accept a new role. Performing the work directly was no longer the responsibility of the department. Their roles was now to set policy, develop standards, order and monitor the work, and ensure work is performed safely and accordingly by the contractor.

One of the main objectives of the outsourcing of highway maintenance was to use private sector forces to deliver the same LOSs as the government forces but at a reduced cost to the tax payers of Alberta. This objective was achieved by using a competitive bid process, managing by standards and performance, reducing government administration, enhancing opportunities for innovation and facilitating economic growth in the private sector. Another significant factor that contributed to the success has been the strong working relationship the department has with its maintenance contractors. The partnering relationship has drawn on the strengths of both parties involved in roadway and bridge maintenance.

The department will continue to draw on the strength of its partnering relationship with the maintenance industry as it looks ahead into the future. Many new challenges wait on the horizon and the department is confident that it will be able to overcome these.

REFERENCES

1. Bowland, J. *Final Phase One Report: Outsourcing of the Maintenance of Primary Highways—Documentation Review.* KPMG Management Consulting, Feb. 5, 1997.
2. Bowland, J. *Final Phase Two Report: Outsourcing of the Maintenance of Primary Highways—Financial and Other Impacts.* KPMG Management Consulting, Feb. 5, 1997.
3. Alberta Transportation, ARHCA, *Sharing Risk and Innovative Solutions in Highway Maintenance Partnership.* Application for the 2001 National Awards of the Canadian Council of Public Private Partnerships, July 9, 2001.
4. Treidler, B. *Alberta Transportation Review of the Provincial Highway Retendering Process Comparing 1995/96 to 2000.* KPMG Management Consulting, June 2001.

PART 2

Pavement Preservation

PART 2: PAVEMENT PRESERVATION

Pavement Preservation Strategy Selection in California

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The California Department of Transportation (Caltrans) has embarked on an ambitious program for pavement preservation and has established a pavement preservation task group (PPTG) to handle activities related to this program. One of the sub-groups is charged with improving the pavement preservation strategy selection process for both asphalt and portland cement concrete (PCC) pavements.

This paper describes the pavement preservation strategy selection process currently used by Caltrans for flexible pavements. It identifies the many factors that are considered in the process of selecting an appropriate maintenance treatment for a pavement. These factors include pavement age and condition, traffic levels, expected future plans, as well as available funding and agency policy. For a properly constructed new pavement, typical pavement preservation treatments include those to delay the onset of distresses or to slow down the progress of the distresses. As the pavement ages, the pavement may become a candidate for routine and contract maintenance (e.g., crack sealing, grinding, seal coats, or thin hot mix overlays), minor or major rehabilitation, and eventually reconstruction.

Determining the appropriate maintenance treatment, based on the pavement condition index of the existing pavement and cost-effectiveness of the treatment, also depends on the timing of the treatment. Once a pavement has been identified for pavement maintenance, a specific treatment is selected to address the specific distress mechanism for the pavement. The most important factors considered when choosing a maintenance treatment include the following:

- **Will the treatment address the distresses present (i.e., will it work)?**
- **Can the required preparation for the treatment be carried out?**
- **Is the treatment cost-effective?**
- **Can the treatment be applied before the situation being addressed changes?**

A discussion of the basic steps in the pavement preservation strategy selection process is presented in this paper. These steps include the following:

- **Assess the existing pavement conditions: The pavement distress mechanisms are identified from field pavement surveys along with the use of a field distress identification manual.**
- **Determine the feasible treatment options: The "feasibility" is determined by a treatment's ability to address the functional and structural condition of the pavement while also meeting any future needs. At this stage, the primary purpose of selecting feasible treatments is to determine if the identified maintenance treatments work for the pavement conditions.**
- **Analyze and compare the feasible options with each other: The feasible options are further compared in terms of cost, life expectancy of the treatment, and extended pavement life benefits**

due to the treatment. To determine cost-effectiveness of each treatment, a life cycle or other cost-effectiveness measure should be made.

This paper also addresses proposed changes to the selection process to include treatments for PCC pavements and to include a more detailed cost-effectiveness approach using life-cycle cost analysis.

INTRODUCTION

The California Department of Transportation (Caltrans) maintenance program has shifted from a reactive effort to a proactive pavement preservation effort. This along with a need for technical support and training in the use of various maintenance treatments prompted Caltrans to develop an advisory guide for the use of various maintenance treatments. The Caltrans Maintenance Technical Advisory Guide (MTAG), developed in 2002, is a technical manual that covers pavement preservation and maintenance principles, materials used in maintenance treatments, treatment selection and individual chapters on the main strategies currently in use by Caltrans (e.g., crack sealing, chip seals, fog seals, slurry seals, and thin maintenance overlays). Guidelines for piloted strategies utilizing micro-surfacing and bonded wearing courses have been developed as companion documents (*1*).

The MTAG was developed to assist maintenance personnel in making better and more informed decisions in selecting and applying maintenance treatments for their highways. It is a reference guide that is used by all types of Caltrans personnel when selecting a maintenance treatment and understanding how the treatment needs to be applied.

The MTAG was designed for several types of uses ranging from general instruction to specific work practice descriptions. The guide was also designed to be used by maintenance managers, maintenance supervisors, superintendents and field personnel. Construction personnel and designers also may find this publication useful.

Organization of MTAG

The MTAG covers all the major treatment types currently used by Caltrans for flexible pavements. The MTAG is organized to allow for the inclusion of any future strategies. For example, additional guidelines have been developed for bonded wearing course pilot projects and microsurfacing pilot projects. Work is also just beginning to develop guidelines for portland cement concrete (PCC) pavement treatments. These new guidelines will eventually be incorporated in the MTAG. The current version of the document resides on the Caltrans website (http://www.dot.ca.gov/hq/maint).

General Strategy Selection Process

The general strategy selection process used in the MTAG considers many factors when selecting an appropriate treatment for a pavement. These factors include pavement age and condition, traffic levels, expected future plans, available funding, and agency policy.

At the network level, a general relationship exists between pavement condition and pavement age. For a properly constructed new pavement, the only treatments required are preventive in nature (maintenance performed to delay the onset of distress). As the pavement ages, it becomes a candidate for routine maintenance (e.g., crack sealing, seal coats, and thin overlays), then rehabilitation, and, finally, reconstruction.

Determining the appropriate maintenance treatment, based on the life-cycle and pavement condition index of the existing pavement, depends on the timing of the treatment. For example, the appropriate maintenance strategy for a relatively new pavement differs from the strategy required for to a pavement nearing the end of its life cycle (Figure 1).

Once the appropriate maintenance strategy has been identified, the specific treatment can be selected based on the specific distress mechanism acting on the pavement. The most important questions to consider when choosing the specific maintenance treatment are

- Does the treatment address the distresses present (i.e., will it work)?
- Can the required preparation for the treatment be carried out?
- Is the treatment cost-effective?
- Can the treatment be performed before the situation being addressed changes?

CURRENT MAINTENANCE TREATMENT SELECTION PROCESS

There are three steps currently included in the maintenance treatment selection process as identified below:

1. Assess the existing conditions. The pavement distress mechanisms are identified using the Caltrans field distress manual and pavement surveys (*2, 3*).
2. Determine the feasible treatment options. The "feasibility" is determined by a treatment's ability to address the functional and structural condition of the pavement while also meeting future needs. Feasibility is not a function of affordability, at this stage of the selection process the purpose is to determine what treatments might work. The MTAG contains the Caltrans matrix for identifying treatment options.

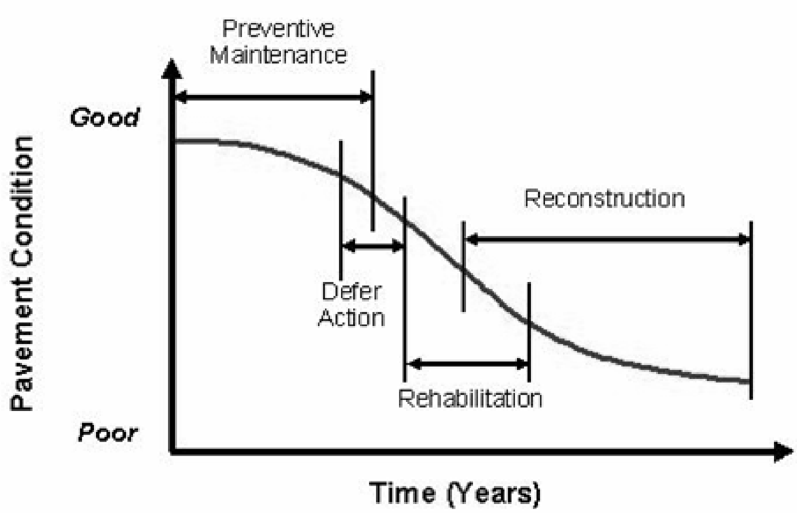

FIGURE 1 Treatment selection based on pavement condition.

3. Analyze and compare the feasible options. Once selected, feasible options are compared in terms of cost, life expectancy, and extended pavement life resulting from the treatment. At this stage, a life-cycle or other cost-effectiveness assessment should be made to evaluate the optimum time to apply the treatment to provide maximum cost-effectiveness.

Each of these is discussed in the following sections.

Assess Existing Conditions

The first step of the treatment selection process is to perform an evaluation of the existing pavement conditions. This evaluation include following three processes:

- Conduct visual site inspection of the pavement conditions or review project information from a database or available records;
- Perform testing on the existing pavement, as conditions require; and
- Define the performance requirements for the treatment.

The Caltrans Field Distress Manual (*2*) or Caltrans Pavement Survey (*3*) may be used to identify pavement distress mechanisms. Treatment methods for the distress mechanisms are discussed in this paper.

It is helpful to assess pavements using a pavement assessment form. A well-developed form promotes uniformity in the assessment process. The use of a pavement history record also helps evaluate the performance of the pavement when contemplating new treatment types and schedules. The district maintenance engineer or other reviewer should fill out on site the pavement assessment form for each pavement being considered for treatment. Figure 2 illustrates an example of a pavement assessment form (*2*) and the type of information that should be collected.

Determine Feasible Treatment Options

Once the pavement condition has been quantified, test results collected and analyzed, and other available data are reviewed, feasible treatments can be identified. In this context, "feasibility" is determined by a treatment's ability to address the functional and structural condition of the pavement while also meeting any future needs. Note that feasibility is not a function of affordability, because at this stage of the selection process the primary purpose is to determine what treatments might work. Figure 3 illustrates the Caltrans matrix for treatment options. For example, type 3 slurry seals will work best on pavements exhibiting raveling or oxidative cracking, but will not work well on pavements that have any significant rutting. They have performed well in most climate zones (except for mountains) and under most traffic conditions. Figure 3 identifies those places where the various maintenance treatments used by Caltrans work and do not work.

Several treatments may be feasible for a given set of conditions. Once the feasible options have been identified, the limitations of each of the options should be taken into account in relation to its suitability in comparison with the other feasible options. Treatment limitations are controlled by such factors as pavement surface deflections, pavement structural condition, roadway curvature, pavement roughness and permeability. The least expensive option that satisfies the maintenance requirements within its limitations should be considered first. This may be determined using

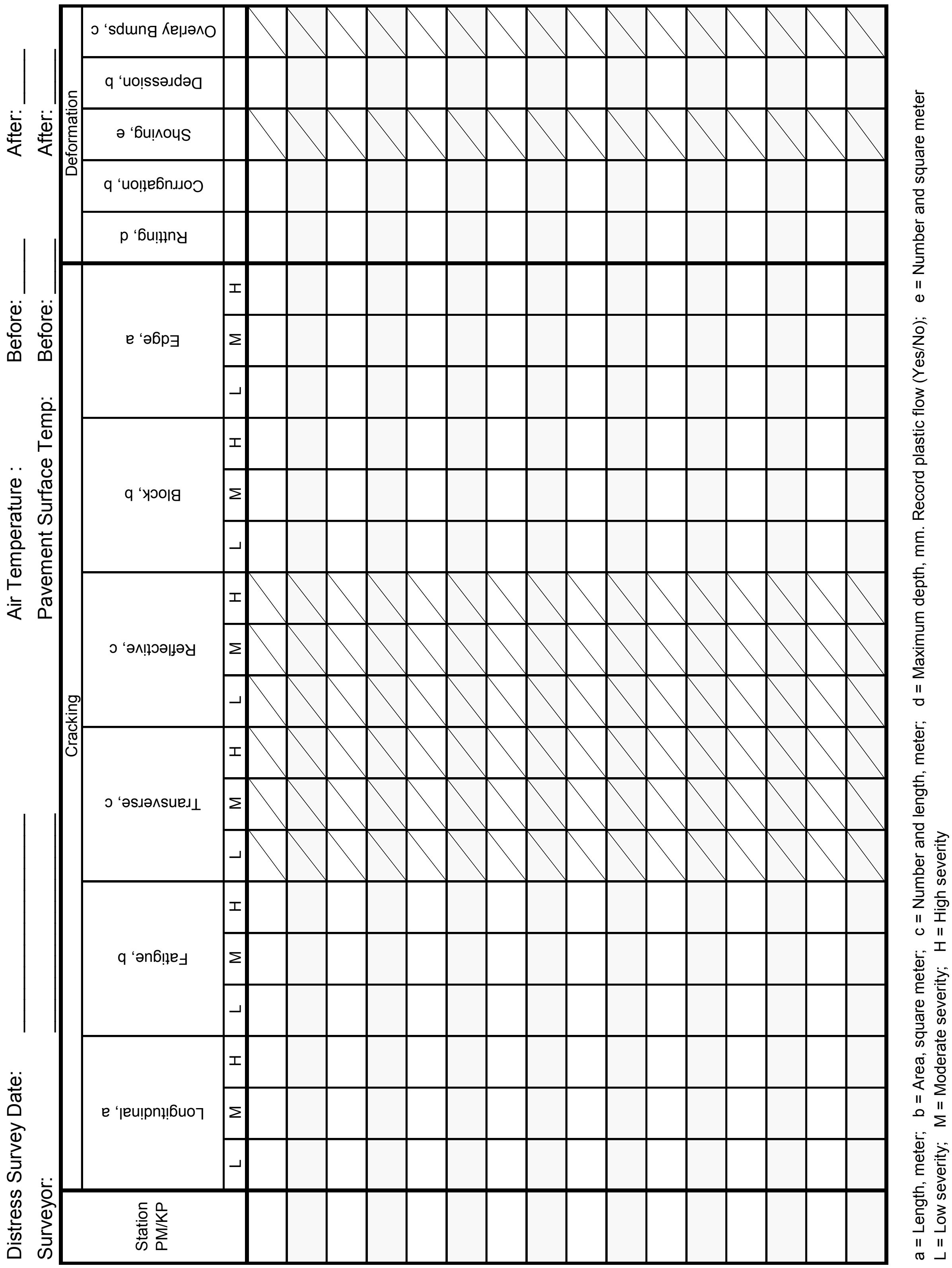

FIGURE 2 Example pavement assessment form—visual (*2*).

Treatment	Pavement Condition										Parameters														
				Rutting		Cracking					Climate				Traffic Volumes										
						Alligator B																			
	Raveling	Oxidation	Bleeding	<13 mm	>13 mm	0 to 10%	10 to 20%	20 to 30%	Longitudinal	Transverse	Desert	Valley	Coastal	Mountains	ADT<5000	ADT>5000<30000	ADT<30000	Night/Cold	Stop Points	Urban	Rural	High Snow Plow Use	Cost Per Lane Mile	Life Expectancy (years)	Equivalent Annual Cost ($/year)
Crack/Joint Seal																									
Emulsion	N	N	N	N	N	F	P	N	F	F	G	G	G	G	G	G	G	N	G	G	G	G	2,500	1 to 2	1,700
Modified (Rubber)	N	N	N	N		G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	2,500	2 to 3	1,000
Low Modulus (Polymer & Asphalt)																									
Fog Seal (See note 1)	F	G	N	N	N	F	P	N	P	P	G	G	G	G	F	N	N	P	F	G	G	F	4,500	1	4,500
Rejuvenator (See note 1)	G	G	N	N	N	F	N	N	N	N	G	G	G	G	G	F	N	N	N	G	G	F	4,500	2 to 4	1,500
Slurry Seals																									
Type II (See note 2)	F	G	N	N	N	F	N	N	N	N	G	G	G	F	G	G	G	P	G	G	G	P	13,000	3 to 4	3,700
Type III	G	G	N	F	N	F	P	N	N	N	G	G	G	F	G	G	G	N	G	G	G	P	13,000	3 to 4	3,700
Microsurfacing																									
Type II (See note 2)	F	G	N	G	N	F	N	N	N	N	G	G	G	G	G	G	G	F	G	G	G	F	16,000	3 to 4	4,500
Type III	G	G	N	G	G	F	P	N	N	N	G	G	G	G	G	G	G	F	G	G	G	F	16,000	3 to 4	4,500
Chip Seal																									
PME – Med. Fine	G	G	N	F	N	G	F	N	P	P	G	G	F	F	G	G	N	N	P	P	G	P	6,500	3 to 5	1,600
PME – Medium	G	G	N	F	N	G	F	N	P	P	G	G	F	F	G	N	N	N	P	P	G	F	6,500	3 to 5	1,600
PMA – Medium	G	G	N	F	N	G	F	P	P	P	G	G	G	G	G	G	N	G	P	P	G	F	12,500	4 to 5	2,800
PMA – Coarse	G	G	N	F	N	G	F	P	P	P	G	G	G	G	G	N	N	G	P	P	G	G	12,500	4 to 5	2,800
AR – Medium	G	G	N	F	N	G	G	F	P	P	G	G	G	G	G	G	N	G	P	P	G	F	20,000	4 to 6	4,000
AR – Coarse	G	G	N	F	N	G	G	F	P	P	G	G	G	G	G	N	N	G	P	P	G	G	20,000	4 to 6	4,000
PM Alternative																									
Conventional OGAC	G	G	P	P	N	G	F	N	P	P	G	G	G	G	G	G	G	P	G	G	G	O	19,500	3 to 4	5,600
PBA OGAC4	G	G	P	P	N	G	F	N	P	P	G	G	G	G	G	G	G	F	G	G	G	P	25,000	4 to 5	5,600
AR (Type O)	G	G	P	F	N	G	G	F	P	P	G	G	G	G	G	G	G	P	G	G	G	P	28,000	4 to 6	5,600
Thin Blanket ACOL																									
Conventional	G	G	P	G	G	G	G	F	P	P	G	G	G	G	G	G	G	G	G	G	G	G	20,000	3 to 5	5,000
PBA	G	G	P	G	G	G	G	G	F	F	G	G	G	G	G	G	G	G	G	G	G	G	25,000	3 to 6	5,600
R (Type G)	G	G	P	G	F	G	G	G	G	G	G	G	G	G	G	G	G	F	G	G	G	G	30,000	5 to 8	4,600
Digouts	P	P	G	N	G	N	N	G	P	P	G	G	G	G	G	G	G	G	G	G	G	G	19,000	5 to 8	2,900

G – Good Performance
F – Fair Performance
P – Poor Performance
N – Not Recommended

Note: 1. Generally used on shoulders, low volume roads, and parking areas. Should not be placed on traveled way by contract until further notice.
2. Generally used on shoulders, parking areas, and locations where a less aggressive surface texture is desired.

FIGURE 3 Caltrans maintenance treatment matrix for flexible pavements.

various cost-effectiveness measures as discussed in the next section. Typical life expectancies and costs for each of the treatments also are included in Figure 3.

Analyze and Compare Feasible Treatment Options

It is likely that there will be several treatments that are identified as feasible. When comparing these different treatments, thought should be given to the treatment placement cost, the life of the treatment, and whether or not the treatment extends the life of the pavement. Additional factors to consider when analyzing and comparing treatment options include: cost-effectiveness, traffic level, construction limitations, and any factors, such as weather, curing times or local issues that affect a specific treatment. The most desirable treatment is the one that provides the greatest benefit (whether that benefit is measured in terms of improvement in condition, extension of pavement life, or even, more simply, the life of the treatment) for the lowest life-cycle costs. At this point a life-cycle or other cost-effectiveness measure should be performed.

Reconstruction and maintenance costs rise as a pavement ages. However, if maintenance and rehabilitation is carried out too early, it will not be cost-effective. There is an optimum time at which maintenance can be performed to provide the maximum cost-effectiveness. Figure 4 shows a typical cost-effectiveness relationship with respect to timing of treatment applications. There are optimum times to place treatments and these need to be established.

Cost-Effectiveness

Caltrans currently calculates cost-effectiveness using the Caltrans Pavement Condition Report (*3*). Project awards and completion records can also be used to determine the cost per lane mile and surface area, and this leads to the evaluation of effectiveness in comparison with other appropriate treatments. However, for an initial assessment a more simplified approach may be employed. This simplified approach is useful as costs and actual bid prices fluctuate. One simplified approach that can be used is the equivalent annual cost (EAC). In this method an equivalent annual cost is calculated using the following equation:

EAC = Unit Cost of Treatment/Expected Life of Treatment (*1*)

At this stage, the treatment that meets the performance requirements with the lowest EAC may be selected. These costs are shown in Figure 3 in the last column. Other, more complex, methods exist (*7*) and may be used to calculate whole of life costing. Caltrans is currently working on establishing a standard life-cycle cost analysis (LCCA) to be used across all units. This is described in more detail later in this paper.

Selection of Maintenance Treatments

The main issues to consider when selecting between accepted treatments listed in the Caltrans treatment selection matrix are

- Performance and constructability and
- Customer satisfaction.

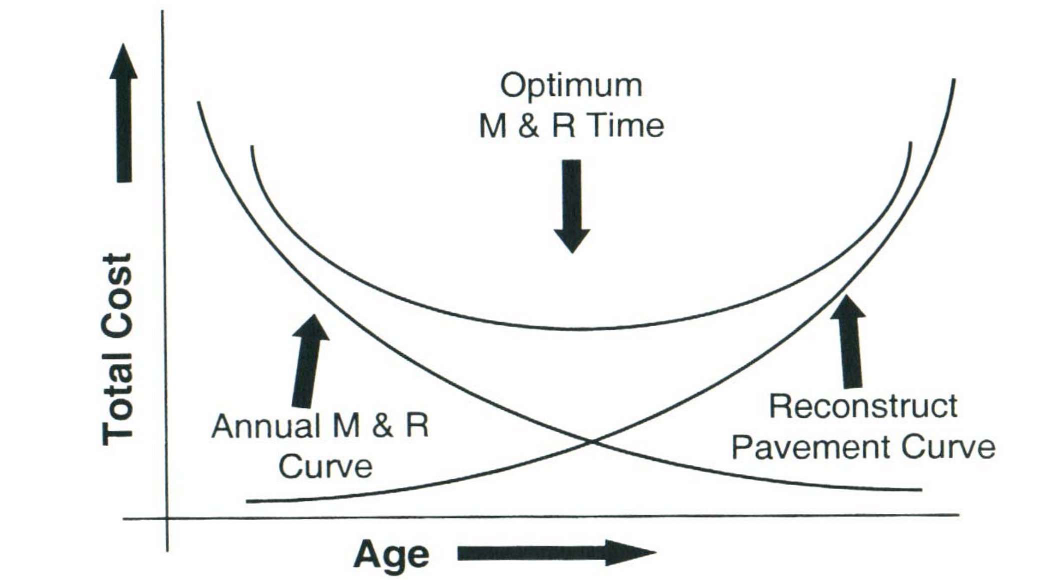

FIGURE 4 Treatment timing versus costs (*6*).

Performance and constructability factors include the expected life of a treatment, seasonal effects on a treatment, existing pavement conditions, the existing pavement structure and the EAC calculated for the treatment. The contractor's experience, materials availability and weather limitations should also be taken into account. The district maintenance engineer or local supervisor should assign ratings based on their individual experience. The ratings are based on the fact that a treatment is suitable when it is properly applied; however, project limitations such as climate conditions and material limitations may prohibit proper procedures from being followed. In situations where new products or material sources are being introduced, a risk factor should be considered, and a lower rating given to these materials. Similarly, if a contractor is unfamiliar with the new product or new material, a lower rating should be given, despite the technical properties of a new product.

Customer satisfaction factors are social factors and include traffic disruption, skid resistance achieved, and noise level. Aesthetic factors such as dust and general appearance are also included. This allows a feasible option to be evaluated on factors other than cost and performance. The most cost-effective and long lasting treatment may not be the right treatment for the right pavement at the right time under some conditions.

The rating factor is the weight, based on overall importance to the job success, assigned to a specific treatment's attribute. The higher the rating, the more significant the attribute's impact on the job's success is. The process is described more fully in the MTAG. This process should be repeated for all potential treatments that meet the feasibility requirements.

PROPOSED ADDITIONS TO THE STRATEGY SELECTION PROCESS

Modifications to the Matrix for Flexible Pavements

Caltrans has recently modified the matrix included in the MTAG to better reflect the practices in the field. Figure 5 presents the new guidelines for selecting effective maintenance treatments as a function of type of distress, climate and traffic. Again, it is possible that several treatments could be used for a given situations. Figure 5 is used in the same way as the matrix presented in Figure 3. It allows one to determine the appropriate maintenance treatment for a given distress, climate and traffic level. It also identifies other conditions that may limit the use of a given treatment such as

- Nighttime paving,
- Cold weather paving,
- Presence of stop/start points,
- Used in urban or rural areas, and
- High snow plow use.

It includes update costs (dollars per lane mile), life expectancy, and EACs.

Figure 6 presents a similar matrix for selecting treatments when only cracking is the distress type being addressed. The use of these matrices will allow the district maintenance engineers or others to select appropriate treatments based on these parameters. Life expectancy, cost and other factors also need to be considered to determine the most cost-effective treatment for a given applications. At the present time, only the EAC approach is considered by Caltrans maintenance.

Inclusion of Concrete Pavement Preservation Treatments

Caltrans currently does not have a selection matrix for maintenance treatments for portland cement concrete pavements. This section of the paper describes the treatments used by Caltrans as well as the trigger points used to apply the treatment. The end result is the development of a proposed selection matrix similar to those developed for asphalt pavements

Types of Treatments

The treatments currently considered by Caltrans for maintenance include the following;

- Crack sealing. Caltrans makes extensive used of crack or joint sealants in jointed concrete pavements. Asphalt emulsions, fiber and asphalt, rubberized asphalt, and silicone sealants have been used. The estimated lives of these treatments vary from 5 to 10 years depending on where they are applied.
- Diamond grinding. Diamond grinding is used extensively as a maintenance treatment to restore smoothness. Estimated lives of the grinding can be 10 to 15 years depending on the traffic and the environmental conditions.

GENERAL GUIDELINES FOR EFFECTIVE MAINTENANCE TREATMENTS

Treatment	Parameters																			
				Rutting		Climate				Traffic Volumes										
	Raveling	Oxidation	Bleeding	<1/2"	>1/2"	Desert	Valley	Coastal	Mountains	adt < 5000	adt>5000<30,000	adt >30,000	Night	Cold	Stop Points	urban	Rural	High Snow Plow use	Cost per lane mile	Life expectancy (years)	Life Cycle Cost ($/Year)
Crack/Joint Seal																					
Emulsion	N	N	N	N	N	G	G	G	G	G	G	G	N	N	G	G	G	G	4,500	1 to 2	3,000
Modified (Rubber)	N	N	N	N	N	G	G	G	G	G	G	G	G	G	G	G	G	G	4,500	2 to 3	1,800
Fog Seal (See note 1)	F	G	N	N	N	G	G	G	G	F	N	N	N	P	F	G	G	F	7,000	1	4,500
Rejuvenator (See note 1)	G	G	N	N	N	G	G	G	G	G	F	N	N	N	N	G	G	F	7,000	2 to 4	2,333
Slurry Seals																					
Type II (See note 1)	F	G	N	N	N	G	G	G	F	G	G	G	N	P	G	G	G	P	13,000	3 to 4	3,714
Type III	G	G	N	F	N	G	G	G	F	G	G	G	N	N	G	G	G	P	13,000	3 to 4	3,714
Microsurfacing																					
Type II (See note 2)	F	G	N	F	P	G	G	G	G	G	G	G	G	F	G	G	G	N	30,000	3 to 4	8,571
Type III	F	G	N	F	P	G	G	G	G	G	G	G	G	F	G	G	G	N	30,000	3 to 4	8,571
Chip Seal																					
PME - Med. Fine	G	G	N	F	N	G	G	F	F	G	G	N	N	N	P	P	G	P	14,000	3 to 5	3,500
PME - Medium	G	G	N	F	N	G	G	F	F	G	N	N	N	N	P	P	G	F	14,000	3 to 5	3,500
PMA - Medium (See Note 3.)	G	G	N	F	N	G	G	G	G	G	G	N	N	G	P	P	G	F	18,000	4 to 5	4,000
PMA - Coarse (See Note 3.)	G	G	N	F	N	G	G	G	G	G	N	N	N	G	P	P	G	G	18,000	4 to 5	4,000
AR - Medium	G	G	N	F	N	G	G	G	G	G	G	N	G	G	P	P	G	F	26,000	4 to 6	5,200
AR - Coarse	G	G	N	F	N	G	G	G	G	G	N	N	G	G	P	P	G	G	26,000	4 to 6	5,200
PM Alternative																					
Conventional OGAC	G	G	P	P	N	G	G	G	G	G	G	G	P	P	G	G	G	P	30,000	3 to 4	8,571
PBA OGAC	G	G	P	P	N	G	G	G	G	G	G	G	F	F	G	G	G	P	30,000	4 to 5	6,667
AR OGAC	G	G	P	F	N	G	G	G	G	G	G	G	F	P	G	G	G	P	40,000	4 to 6	8,000
AR OGAC High Binder (HB)	G	G	P	F	N	G	G	G	G	G	G	G	F	P	G	G	G	P	45,000	4 to 6	9,000
Gap Graded RACOL	G	G	P	G	F	G	G	G	G	G	G	G	F	F	G	G	G	G	45,000	4 to 6	9,000
Thin Bonded Wearing Course (BWC)	G	G	P	P	P	G	G	G	G	G	G	G	F	F	G	G	G	G	50,000	4 to 6	10,000
Dense Graded ACOL																					
Conventional	G	G	P	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	30,000	2 to 5	8,571
PBA	G	G	P	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	35,000	3 to 5	8,750
AR	G	G	P	G	F	G	G	G	G	G	G	G	F	F	G	G	G	G	45,000	4 to 5	10,000
Digouts	P	P	G	N	G	G	G	G	G	G	G	G	G	G	G	G	G	G	125,000	4 to 6	25,000

Last revised 9-9-02 G-Good Performance F - Fair Performance P - Poor Performance N - Not Recommended

Note: 1. Usually limited to shoulders, low volume roads and parking areas.

Note: 2. Generally used on shoulders, parking areas and locations where less aggressive surface is desired.

Note: 3. Under evaluation. Please consider other strategy at this time.

FIGURE 5 General guidelines for effective maintenance treatments (1 in. = 25.4 mm).

- Partial slab repair. This treatment is used to repair problems such as spalling. The estimated live of this treatment varies from 8 to 10 years or more.
- Full slab replacement. Caltrans also replaces isolated full slabs where the slab has exhibited extensive cracking or is unstable. The estimated lives of this treatment range from 8 to 15 years.
- Dowel bar retrofit. Caltrans has used dowel bar retrofit as a pavement preservation strategy. Some projects have performed well while others have experienced early failures due to bonding problems between the grout and the existing concrete. This treatment is expected to be used more once the construction problems have been addressed. However, the pool of candidates in California is considered small due to pavement age and distress levels. The estimated lives of this treatment range from 8 to 15 years.
- Slab stabilization. Slab stabilization using various grouts has met with some success. More recently slabs are being stabilized with expansive injected polymers. Expected lives for this treatment have not yet been established by Caltrans.

These treatments are similar to those proposed by FHWA for pavement preservation treatments for concrete pavements (*12*). Historically, Caltrans has not done much on pavement preservation for concrete pavements focusing primarily on crack sealing.

Identifying Trigger Points for Each Treatment

Caltrans is in the process of establishing trigger points for each of the above maintenance treatments (that is when in the pavement’s life should the given treatment be applied). The trigger points that are discussed below are based on national experiences as well as the experience within the division of maintenance–Caltrans. Other factors that might affect the trigger points such as traffic or climate or available construction windows are also briefly addressed in the following discussion:

- Crack sealing. Cracks should be seals about every 5 years or when the crack width is about 3.2 mm.
- Diamond grinding should take place when faulting is about 3.2 mm or when the ride (international roughness index) reaches a level of about 1.5 m/km.
- Partial slab repair. This treatment should be used when the distress is located on the surface and the distressed area is small (less than 1 m^2).
- Full slab replacement. This treatment is used when the isolated slab is exhibiting third-stage cracking and it is unstable.
- Dowel bar retrofit. Used when load transfer is less than 60% and faulting is 2.5 mm or higher. The pavement also has to be in good condition with a maximum of 10% cracking.
- Slab stabilization. This technique is seldom used in California, and its use is limited to situations when voids beneath the slab are greater than 6.4 mm, and when the pavement has little structural damage. This work may have to be done concurrently with other pavement preservation activities.

GENERAL GUIDELINES FOR EFFECTIVE MAINTENANCE TREATMENTS ON CRACKS

	Type of Cracking														
	Alligator "A"			Alligator "B"			Alligator "C"			Longitudinal/Transverse			Edge		
Criteria	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Width / Area	<1/4" or <10%	>1/4", <1/2" or >10%, <20%	>1/2" or >20%, <30%	<1/4" or <10%	>1/4", <1/2" or >10%, <20%	>1/2" or >20%, <30%	<1/4" or <10%	>1/4", <1/2" or >10%, <20%	>1/2" or >20%, <30%	<1/4"	>1/4", <1/2"	>1/2"	No Material Loss	>0%, <10% Material Loss	>10% Material Loss
Treatment															
Crack/Joint Seal (See Note 5)															
Emulsion	N	F	N	N	P	N	N	N	N	G	F	N	G	P	P
Modified (Rubber)	N	G	P	N	P	N	N	P	N	P	G	F	P	P	P
Fog Seal (See note 1)	G	N	N	G	N	N	F	N	N	F	N	N	F	P	P
Rejuvenator (See note 1)	G	N	N	G	N	N	F	N	N	F	N	N	F	P	P
Slurry Seals															
Type II (See note 1)	F	N	N	F	N	N	F	N	N	F	N	N	F	P	P
Type III	F	P	N	F	P	N	F	P	N	F	P	N	F	P	P
Microsurfacing															
Type II (See note 2)	G	N	N	F	P	N	F	P	N	F	N	N	P	P	P
Type III	G	P	N	F	P	N	F	P	N	F	N	N	P	P	P
Chip Seal															
PME - Med. Fine	G	P	N	G	F (See Note 4)	N	G	P (See Note 4)	N	P	P	N	P	P	P
PME - Medium	G	P	N	G	F (See Note 4)	N	G	P (See Note 4)	N	P	P	N	P	P	P
PMA - Medium (See Note 3.)	G	P	P	G	F (See Note 4)	P	G	P (See Note 4)	P	P	P	N	P	P	P
PMA - Coarse (See Note 3.)	G	P	P	G	F (See Note 4)	P	G	P (See Note 4)	P	P	P	N	P	P	P
AR - Medium	G	G	F	G	G	F	G	F (See Note 4)	F	P	F	F	P	P	P
AR - Coarse	G	G	F	G	G	F	G	F (See Note 4)	F	P	F	F	P	P	P
PM Alternative															
Conventional OGAC	G	F	N	G	F (See Note 4)	N	G	F (See Note 4)	N	G	F	P	P	P	P
PBA OGAC	G	F	N	G	F (See Note 4)	N	G	F (See Note 4)	N	G	F	P	P	P	P
AR OGAC	G	G	F	G	G	F (See Note 4)	G	G	F	G	F	P	P	P	P
AR OGAC High Binder (HB)	G	G	F	G	G	F (See Note 4)	G	G	F	G	F	P	F	F	F
Gap Graded RACOL	G	G	G	G	G	F (See Note 4)	G	G	G	G	F	P	G	G	G
Thin Bonded Wearing Course (BWC)	G	G	G	G	G	F (See Note 4)	G	G	F	F	F	P	P	P	P
Dense Graded ACOL															
Conventional	G	G	F	G	G (See Note 4)	P (See Note 4)	G	G	F	P	F	F	N	F	F
PBA	G	G	G	G	G (See Note 4)	P (See Note 4)	G	G	G	P	F	F	N	F	F
AR	G	F	P	F	P (See Note 4)	P	G	F	P	P	P	F	N	F	F
Digouts	N	N	F	N	N	G	N	N	G	N	F	F	N	F	G

Last revised 9-9-02

G-Good Performance F-Fair Performance P - Poor Performance N - Not Recommended

Note: 1. Usually limited to shoulders, low volume roads and parking areas.

Note: 2. Generally used on shoulders, parking areas and locations where less aggressive surface is desired.

Note: 3. Under evaluation. Please consider other strategy at this time.

Note: 4. Effective when proper Prep Work has been performed.

Note: 5. Per Maintenance Manual, Cracks <1/4 inch - Crack Seal Not Recommended.

FIGURE 6 General guidelines for maintenance treatments on cracks (1 in. = 25.4 mm).

Strategy Selection Guidelines

Figure 7 presents a proposed matrix for concrete pavements based on the strategies that Caltrans uses for PCC pavements and the trigger points discussed above. This matrix is a first draft of the proposed process to be reviewed by concrete pavement specialists. Further development work is expected on this matrix before it will be adopted statewide. The matrix includes those situations when a given treatment should be employed and identifies estimated lives and costs for the treatments. EAC for each treatment will be calculated once final lives and cost data become available.

Determining the Cost-Effectiveness of the Treatments

This section of the paper describes the process that is being developed to evaluate the cost-effectiveness of the various maintenance treatments for both asphalt and PCC pavements. Caltrans has adopted the FHWA real cost model for all cost analysis (*11*). This model allows for both deterministic and a probabilistic approach to evaluating cost-effectiveness. Shown in Figure 8 is a proposed approach by Caltrans to the evaluation of cost-effectiveness of maintenance treatments. Specific items to be used by Caltrans (*13*) in running the real cost program are under development at this time. Items that are being considered include analysis period, discount rate,

Treatment	Trigger (National)	Climate				Average Daily Traffic			Life of Treatment (Year)	Estimated Cost ($)
		Desert	Valley	Coastal	Mountain	<5,000	>5,000;<30,000	>30,000		
Crack sealing	>3.2 mm	Apply to all climate and traffic conditions. Work is underway to evaluate the effect of climate and traffic conditions.							5–10	4.2–7.2/m^2
Diamond grinding	Faulting >3.2 mm; ride 1.5 m/km								10–15	2.4–12/m^2
Partial slab repair	Surface distress: small patches <1 m^2								8–10	177–353/m^3
Isolated slab replacement	Third stage cracking or unstable slabs								8–15	4,000–8,000/slab
Dowel bar retrofit	Loss in load transfer <60%; faulting >2.5 mm; maximum 10% cracking								8–15	24–30/m^2
Slab stabilization	Voids >6.4 mm								Not enough experience	

FIGURE 7 Proposed Caltrans maintenance treatment matrix for concrete pavements.

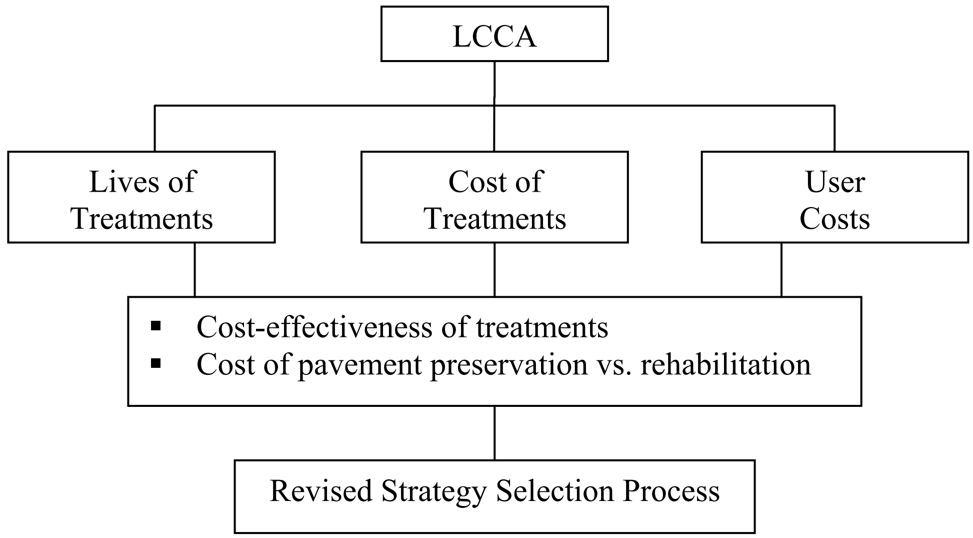

FIGURE 8 Proposed work on cost-effectiveness.

traffic characteristics, agency and user costs, maintenance costs, and other pertinent construction costs.

The process requires coming up with the following data to perform the needed analyses.

- Estimated lives (or live extension) of each treatment. These data are being established using the experiences of the district maintenance engineers and the pavement management system. Typical lives of each of the treatments are shown in Figures 5 and 7. Life extensions for the various treatments are not yet readily available, but are expected to be obtained from the pavement management system or from the experience of maintenance personnel. Life extensions are expected to be affected by the timing of the treatment and the condition of the pavement on which it is placed.
- Cost data for the various treatments are summarized in Figures 5 and 7. Cost data includes not only the cost of the treatment, but also the cost of the traffic control and any repair work needed prior to applying the treatment. Cost data are consistent across treatments. These need to be reviewed and updated periodically as the cost of the treatments changes over time.
- User delays for each treatment can vary and need to be considered in the cost analysis. Because of the time differences in applying the different treatments, the user delays costs associated with each treatment will vary. These costs need to be established and Caltrans is working on developing these costs for each of the treatments. As would be expected, the user delays costs will vary depending on the traffic conditions and the time of day the work is undertaken.

Once the estimated lives and costs are fully established for the various pavement preservation treatments, various scenarios will be run using the real cost program to establish cost-effectiveness of treatments for both asphalt and PCC pavements.

DISCUSSION

The development of the MTAG has been a giant step toward providing guidelines for Caltrans personnel in the selection of pavement preservation treatments. The task was a very challenging one because it had to meet the expectations of not only Caltrans but also industry.

The strategy selection guidelines will improve the Caltrans pavement preservation program. This effort, which emphasizes the inclusion of the LCCA and the refinement of the concrete pavement preservation techniques, will establish a rational and systematic approach to pavement preservation. Caltrans has been using preventive maintenance treatments routinely for asphalt pavements. This ambitious program of preventive maintenance treatments has prompted Caltrans moving into providing similar guidance for pavement preservation on concrete pavements.

The MTAG has received peer review from the national Pavement Preservation Expert Task Group, the California Pavement Preservation Task Group, the Caltrans Pavement Standards Team, Caltrans maintenance personnel, as well as from many experts from industry and public agencies. The MTAG included many state-of-the-practices from many reference sources. The FHWA is currently funding the development of a web-based training to disseminate information contained in the MTAG. The training materials are scheduled to be available in late 2006. With this information, the field personnel should be able to train themselves in the use of the processes described in the MTAG.

Similar work is still needed for the various maintenance treatments used by Caltrans for concrete pavements. This work effort is currently in the planning stages. New sub-groups within the pavement preservation task group will be established to address these specific needs.

CONCLUSIONS AND RECOMMENDATIONS

Caltrans ambitious pavement preservation program has prompted the development of the MTAG. The strategy selection process included in the MTAG is now a standard practice for use by Caltrans maintenance personnel. The MTAG is intended to be a dynamic and flexible document and it is recommended that the document be updated on an as-needed basis. In the near future it is likely that the following be included:

- Strategies for pavement preservation for concrete pavements.
- Other strategies as they are adopted by Caltrans (e.g. recycling).
- More quantitative information on life extension or life of the treatment.
- Cost-effectiveness of various treatments using a LCCA approach.

REFERENCES

1. California Department of Transportation. *Caltrans Pavement Survey*, Sacramento, 2000.
2. California Department of Transportation. *Guide to the Investigation and Remediation of Distress in Flexible Pavements: Field Manual*, Sacramento, July 2002.
3. California Department of Transportation. *Maintenance Technical Advisory Guide* (MTAG), Sacramento, April 2002. http://www.dot.ca.gov/hq/maint.

4. FHWA. *An Overview of Surface Rehabilitation Techniques for Asphalt Pavements*, FHWA-PD-92-008. FHWA, U.S. Department of Transportation, 1992.
5. Galehouse, L., J. Moulthrop, and R. G. Hicks. Principles of Pavement Preservation: Definitions, Benefits, Issues and Barriers. *TR News*, No. 228, September–October 2003, pp. 4–9.
6. Hicks, R. G., S. B. Seeds, and D. G. Peshkin. *Selecting a Preventative Maintenance Treatment for Flexible Pavements*. Report FHWA-IF-00-027, FHWA, U.S. Department of Transportation, 2000.
7. Hicks, R. G., and D. Jackson. Benefits of Pavement Maintenance—An Update. Western Pavement Maintenance Forum, Sacramento, California, 1998.
8. Moulthrop, J., T. Thomas, W. Ballou, and H. King. Choose the Right Tool for the Right Distress. *Asphalt Contractor*, September 1999.
9. O'Brien, L. G. *NCHRP Synthesis of Highway Practice 153*: *Evolution and Benefits of Preventative Maintenance Strategies.* TRB, National Research Council, Washington, D.C., 1989.
10. Scholz, T., R. Hicks, and J. Moulthrop. Preventive Maintenance vs. Reconstruction: Life-Cycle Cost Analysis of Various Options. Proc., International Society of Asphalt Pavements, Denmark, 2002.
11. FHWA. *Life Cycle Cost Analysis Real Cost User Manual*. Office of Asset Management, FHWA, U.S. Department of Transportation, May 2004.
12. FHWA. Pavement Preservation Definitions. Memorandum, FHWA, U.S. Department of Transportation, September 12, 2005.
13. Caltrans. *Caltrans LCCA Study Progress Summary*. Sacramento, November 18, 2005.

PART 2: PAVEMENT PRESERVATION

Study of the Cost-Effectiveness of Various Flexible Pavement Maintenance Treatments

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Debate over the various treatments for extending the life of deteriorated flexible pavements has taken place for several decades. Yet, there is little consensus on the relative merits of each treatment. Thus, there has been an on-going need for objective performance information on the various available treatments. Recently, the Greenville County, South Carolina, Department of Public Works facilitated a comprehensive review of pavement performance under the county's pavement maintenance program. The review provided the potential to independently quantify the relative benefits of various maintenance techniques, including in-place cold mill recycling, full-depth patching, and paving fabric—all followed by an asphalt overlay—as well as the use of only an asphalt overlay. This paper presents the tabulation of data for the 1997–1998 maintenance year that included maintenance of 370 roads. The data includes the pavement condition at time of maintenance, the selected pavement maintenance technique and associated costs, and the recent condition of the maintained roads. Using all available information, an evaluation of the data was made to assess the post-maintenance pavement performance and the cost-effectiveness of the various treatments used.

BACKGROUND

Greenville County, South Carolina, currently maintains approximately 1,600 centerline miles of road, and due to significant growth in the county, more mileage is being added every year. Greenville County has over a decade of documented experience with a variety of rehabilitation and resurfacing techniques, including a road improvement program known as Prescription for Progress (PFP), Paving County Roads initiated by Greenville County in 1997.

In 2002, Greenville County Department of Public Works (GCDPW) decided that there was a need for a periodic evaluation of current road improvement methods and proposed an independent study of available information. A desired scope of study was developed by the GCDPW and provided the basis for this investigation. Paving fabric has been commonly used as one of the road improvement techniques in Greenville County. Because of this, the Geosynthetic Materials Association agreed to fund the study and retained the author to perform the study.

Because of the uncertainty of the quality and quantity of available data, the study was undertaken in two phases. Phase 1 was essentially a pilot study that included only 34 roads. The Phase 1 study suggested that the cost effectiveness and performance-enhancing capability of various treatments is related to the pavement condition at the time of the maintenance treatment. The follow-up Phase 2 study expanded the evaluation to include all 370 roads receiving maintenance treatments in the first year (1997–1998) of the PFP. In this study the term "road" refers to a road or portion of a road receiving a specific maintenance treatment and characterized by a single pavement condition rating.

PHASE 1 (PILOT) STUDY FINDINGS

The primary objective of the Phase 2 study was to expand the data included in the evaluation in order to validate (or refute) the findings of Phase 1. The limited data evaluated in Phase 1 suggested the following:

- In-place cold mill recycling and an overlay is most cost effective and produces the greatest reduction in the rate of road degradation when used with pavements that have surface condition ratings below 30 on a 100-point scale.
- When the pavement surface condition rating is between approximately 35 and 65, the use of paving fabric with a minimum 1½-in. overlay appears to provide the greatest cost-effectiveness and reduction in the rate of road degradation.
- When the pavement surface condition rating is above 70, both a simple asphalt overlay and a fabric–overlay system appear to provide comparable performance and cost effectiveness.

SCOPE OF WORK FOR PHASE 2

All roads included in the Phase 2 study received one of the following maintenance treatments in the first year of the PFP: in-place cold mill recycling (full-depth rehabilitation) and an overlay; patching followed by paving fabric and an overlay; paving fabric and an overlay; or overlay only. The Phase 2 study included the following five steps:

1. Compile a listing of roads rehabilitated or resurfaced in the 1997–1998 PFP programs including the actual associated maintenance treatment costs.
2. Add the most recent pavement condition index (PCI) assessment and the associated date.
3. Estimate (project) the actual road condition (PCI) at the time of 1997–1998 maintenance.
4. Calculate a cost-effectiveness value for each road based on the cost of the maintenance treatment used and the amount of degradation occurring between the time of maintenance and the 2003 road evaluation.
5. Identify trends in the data related to performance of the various rehabilitation–resurfacing techniques.

For the comprehensive review, the following sources of information were used:

- Pavement evaluation reports by Eckrose–Green for years 1994–1996;
- Characteristic pavement degradation curves for Greenville County roads;
- 1997–1998 PFP database;
- Database of 2003 road condition ratings for the roads included in the 1997–1998 PFP.

The results of the Phase 2 study were used to assess the performance and cost effectiveness of currently used road rehabilitation–resurfacing techniques.

DATA REVIEW AND TABULATION

The 1997–1998 PFP program database provided a detailed record of the types of maintenance treatment used on each road, along with actual cost and quantity data. Several three-ring binders of pavement condition data generated between 1994 and 1996 provided relatively recent objective measures of actual road conditions. In cases where roads received different treatments at different segments along the road's length as part of the 1997–1998 program, the different segments were treated as individual roads and assigned different condition ratings, if available. The following information was compiled into detailed tables to facilitate the evaluation.

- Road number;
- Pavement maintenance method and unit costs (1997–1998 are shown in Table 1);
- Road condition rating (1994–1996 rating);
- Projected road condition rating at the time of the 1997–1998 maintenance; and
- 2003 road condition rating.

TABLE 1 Typical Maintenance Treatment Unit Costs

Maintenance Treatment (Material + Labor)	Unit	Unit Price ($)
*Surface, Type 1, 1c, 3 or Binder	ton	38.90
Full-depth asphalt patching	square yard	19.38
B S T, single treatment, Type 3	square yard	0.75
Cold process recycling	square yard	2.14
Crusher run for cold recycling	ton	11.00
Ashpalt emulsion CRS-2 for recycle	gallon	0.66
Maintenance stone	ton	14.55
Set up stone base	square yard	3.00
Backfill material for shoulders	cubic yard	22.00
Grade shoulders	foot	0.68
Ditchline regrading	foot	0.92
Milling, curb reveal	square yard	4.40
Nonwoven paving fabric	square yard	0.72
AC-20 asphalt for paving fabric	ton	165.00
Paving markings	foot	0.15
Water valve adjustment	each	25.00
Manhole adjustment	each	50.00
18-in. RCP, >24 ft	foot	69.00
18-in. RCP, <24 ft	foot	75.00
Seeding	square yard	0.45

* Approximate conversion: 0.1–0.11 T/sy (2.25–2.5 in.)

DATA EVALUATION

The compiled data facilitated the following evaluations:

- Rate of road surface degradation between the last available road condition survey (Eckrose–Green 1994–1996) and the 1997–1998 PFP maintenance;
- Rate of road surface degradation between the 1997–1998 PFP maintenance and the comprehensive 2003 road condition surveys;
- Unit cost of each pavement maintenance technique (in 1997–1998);
- Rate of depreciation of maintenance costs (1997–1998–2003) based on road surface degradation.

1997–1998 Premaintenance Condition

The contractor recommended—and the county approved—the maintenance treatment to be used for each road (i.e., recycle–overlay versus patching–paving fabric–overlay versus overlay only) based on the condition of the pavement at the time of maintenance. The contractor was required to warrant the road performance for a 5-year period. The only available quantitative assessment of the existing pavement condition, and the ratings used to guide the county's selection of roads for the program, was the 1994–1996 Eckrose–Green ratings. No maintenance had been performed on these roads since the last condition survey. Unfortunately, this means that as many as 4 years could have passed since the last quantitative road evaluation. This required the road condition (PCI/OCI) at the time of maintenance to be projected from the known 1994–1996 conditions. Assumed degradation rates were used in the Phase 1 study. Characteristic pavement degradation curves specific to Greenville County were used for Phase 2. The characteristic curves were developed by the county engineering office in 1991 as part of an earlier research project. Individual characteristic curves were generated for new roads and for existing roads. An average characteristic curve was derived from these two curves for use in the Phase 2 study, since it was not known which roads had had previous maintenance. The characteristic pavement degradation curve used to project the 1997–1998 premaintenance pavement condition from the last available documented condition determined at various times between 1994 and 1996 is shown in Figure 1.

Projecting the pavement condition at the time of maintenance based on the county's characteristic degradation curve produced a large number of roads with ratings of zero. This was considered consistent with the PFP's stated intent to deal with the worst roads first.

Measuring Performance

In the Phase 1 study, two measures of performance were used to evaluate the data. First, a depreciation cost was used to determine the cost effectiveness of each type of treatment and represents the value of the treatment "used up" over the time period. Second, a degradation ratio was used to evaluate the improved rate of reduction in the pavement condition after the 1997–1998 treatment as compared to the rate prior to 1997–1998, and, theoretically, facilitates an assessment of "before versus after" performance for each treatment technique. The Phase 2

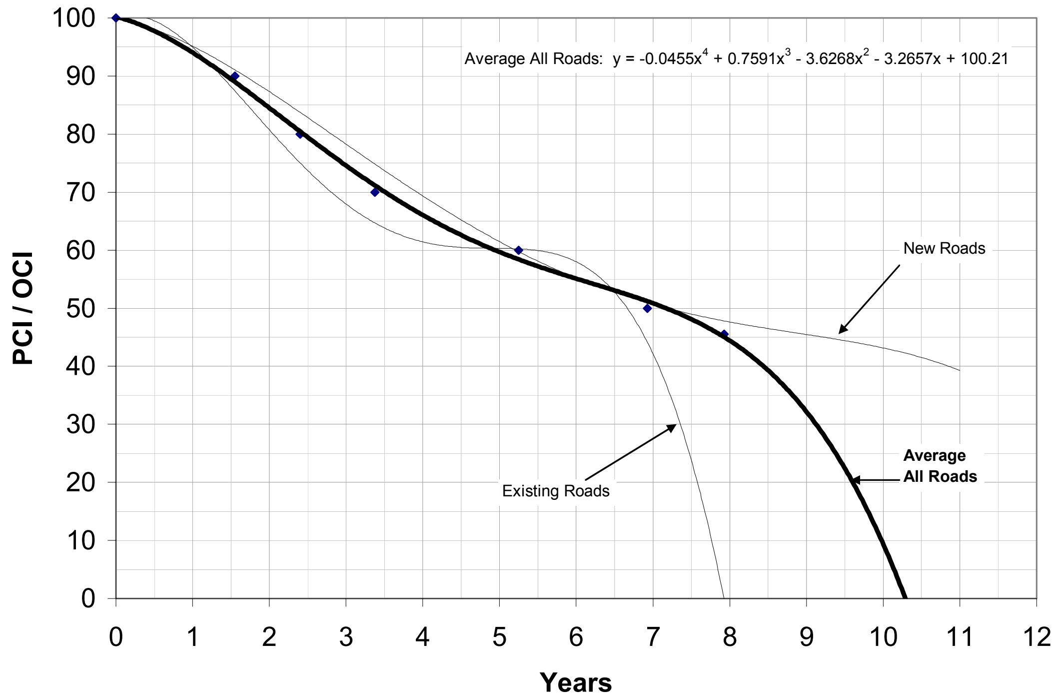

FIGURE 1 Greenville County characteristic pavement degradation curve—average of new and existing roads.

study used only the depreciation cost as the measure of performance, since "before" performance proved much less certain to determine. The depreciation cost in cost per square yard per year was calculated as follows:

Depr. Cost = Unit Cost * {[(100 – latest rating)/100] / (latest rating date – maintenance date)}

Summary performance data have been tabulated in Table 2. The evaluation included dividing the roads that received patching, fabric, and overlay into subsections that received patching along with the fabric and overlay and those that received only fabric and overlay.

TABLE 2 Summary of All Road Performance Data

Summary Data	Recycle and Overlay Roads (R/O)	Patch–Fabric–Overlay (PFO)		Fabric–Overlay (FO)			Overlay Only Roads
		Entire PFO Roads	PFO-only Subsections	FO-only Subsections	FO-only Roads	Avg. All FO	
Number of roads	146	177	177	177	28	205	19
Average initial condition (PCI)	16	20	0	20	23	21	37
Average depreciation cost ($/sy/yr)	0.18	0.16	0.55	0.11	0.11	0.11	0.10

Depreciation Costs

The relationship for each type of maintenance treatment between the depreciation cost and the initial pavement condition were determined, using the characteristic pavement degradation curve (Figure 1) for projecting the initial pavement condition at the time of the 1997–1998 maintenance. The depreciation cost for each road versus its initial pavement condition is presented in Figures 2, 3, and 4. A third order polynomial trendline was fitted to the data for each type of maintenance treatment. This type of trendline was found to provide the highest correlation to the data in both Phase 1 and 2 studies. Figures 3 and 4 remove the data points and present only the trendlines in order to more clearly demonstrate the relative performance of the different maintenance treatments. The much greater size of the database, along with allowing the contractor to choose the maintenance treatment based on a visual (qualitative) assessment, has apparently created greater variability in the Phase 2 data. Still, the chosen trendlines provide a clear indication that the cost-effectiveness of each treatment is related to the road condition at the time of maintenance, as expected.

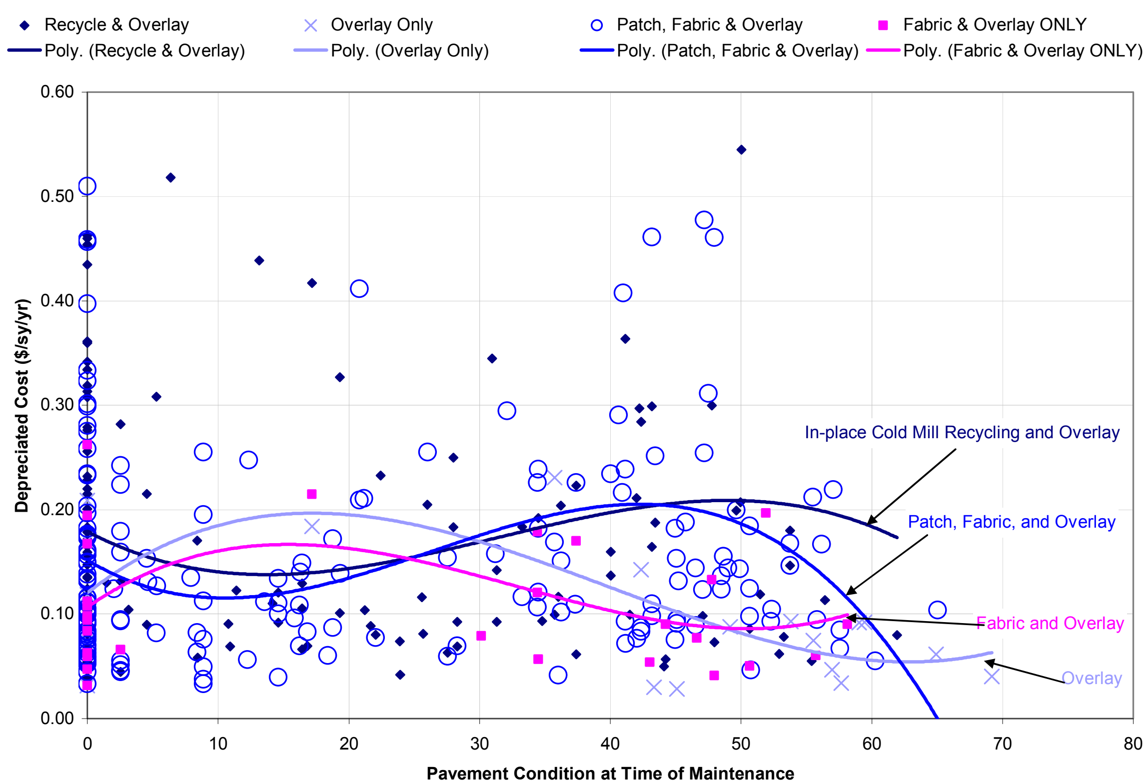

FIGURE 2 1997–1998 and 2003–2004 PFP data and treatment trends.

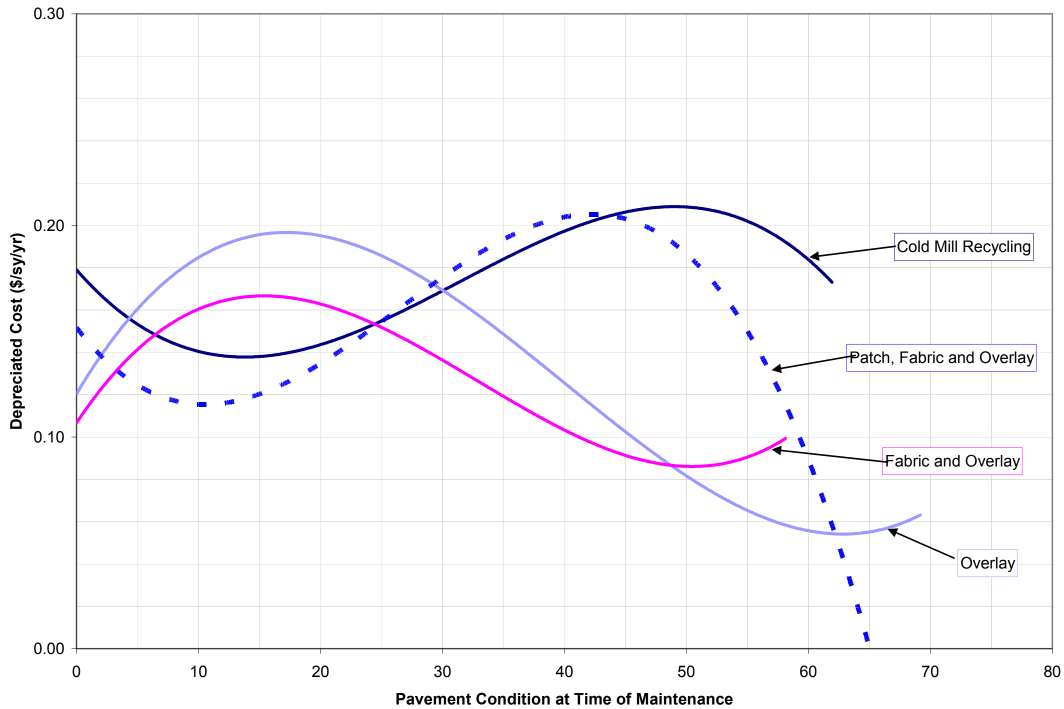

FIGURE 3 1997–1998 and 2003–2004 PFP treatment trends only.

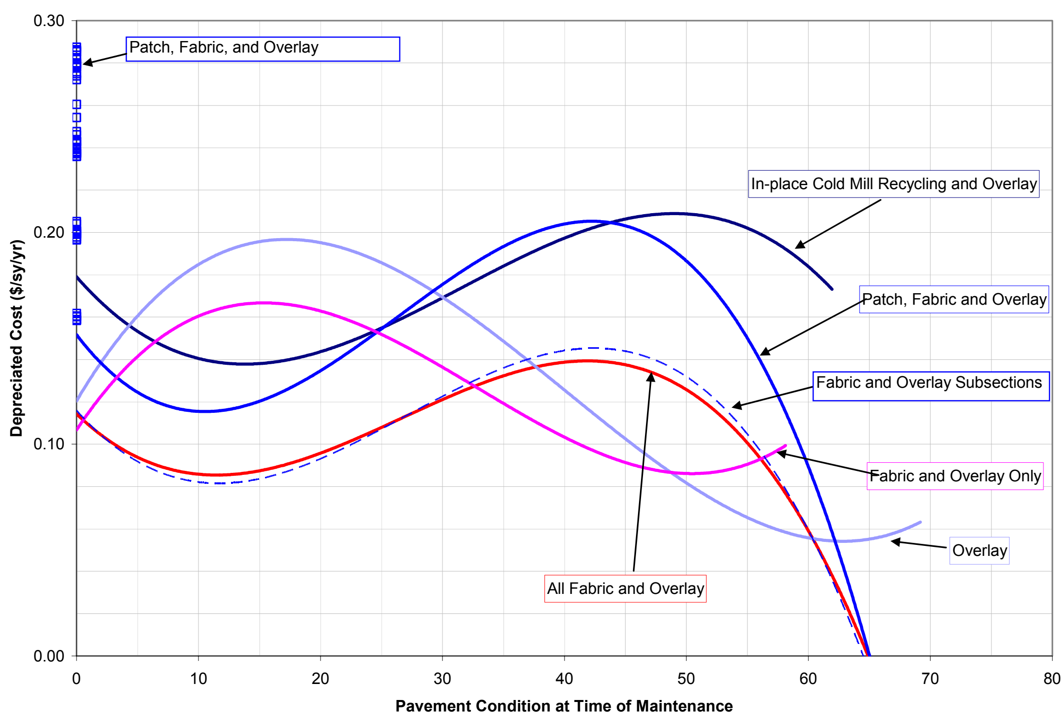

FIGURE 4 1997–1998 and 2003–2004 PFP treatment trends only (including subsections).

CONCLUSIONS

The data compiled and evaluated in the Phase 1 (pilot) study focused on only 34 roads that had received a maintenance treatment as part of the county's 1997–1998 pavement maintenance program. The subsequent Phase 2 study, reported herein, was designed to validate (or refute) the Phase 1 indications by evaluating the entire 1997–1998 PFP database of 370 roads.

The Phase 2 study appears to validate the Phase 1 conclusion that the cost-effectiveness and performance-enhancing capability of various treatments is indeed related to the pavement condition at the time of the maintenance treatment. The more extensive data involved in Phase 2 has more clearly defined the cost-effectiveness of the various treatment types as follows, based on Figure 3:

- In-place cold mill recycling–overlay and patching–fabric–overlay strategies are comparably cost effective and produce the greatest cost effectiveness of the treatments evaluated when used with pavements that have surface condition ratings below 25 on a 100-point scale.
- When the pavement surface condition rating is between approximately 25 and 50, the use of paving fabric with a 1½- to 2-in. thick overlay appears to provide the greatest cost effectiveness and reduction in the rate of road degradation.
- When the pavement surface condition rating is above 50, both a simple asphalt overlay and a fabric–overlay system appear to provide comparable performance and cost effectiveness. Further study of the relative cost effectiveness of treatments when the existing pavement condition is above 50 is needed because this evaluation included very few roads in this condition as a result of the county's "worst first" strategy.

Figure 4 breaks out the fabric–overlay subsections from the roads that received local areas of patching along with fabric and an overlay. When this subsection data is combined with that from roads that received only fabric–overlay, the resulting curve fit suggests it may always be more cost effective to use fabric rather than in-place cold mill recycling when patching is not required.

As can be seen in Figure 2, there is much scatter in the data. Yet, the data may be quite accurate considering that the decision of which maintenance treatment to use was, by contract, left up to the contractor based on his judgment and willingness to warrant the results. Another contributor to the scatter in the data may be the uncertainties associated with assigning a pavement condition and, further, with estimating the pavement condition at the time of maintenance. Ideally, an accurate pavement condition survey would be performed immediately prior to maintenance and an objective decision made as to what treatment to use. Finally, it must be noted that, although a target overlay thickness of 2.25 to 2.5 in. (0.1 to 0.11 T/sy) was expected by the county, the actual thickness frequently ranged as low as 1.9 in. (0.85 T/sy), or lower. This wide range in the actual overlay thickness no doubt contributed to the variability in the data and could be expected to significantly affect long-term pavement performance.

It is hoped that this study will encourage more objective maintenance treatment decision making.

ACKNOWLEDGMENT

The author would like to thank and commend Greenville County for opening its voluminous records to independent review and evaluation. Additionally, financial support for this study by the Geosynthetic Manufacturers Association is appreciated.

REFERENCE

Sprague, C. J. *The Study of Pavement Maintenance Techniques Used on Greenville County Maintained Roads*. Report to the Greenville County Department of Public Works, 2005.

PART 3

Roadside Maintenance

PART 3: ROADSIDE MAINTENANCE

PennDOT's Roadside Spray Future with RoSA

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NATE RECK
GeoDecisions

This paper will describe the Roadside Spray Application (RoSA) developed for the Pennsylvania Department of Transportation (PennDOT). The purpose of this web-based geographic information system (GIS) application is to assist PennDOT's district roadside specialists in managing and coordinating herbicide spray activities along state highways throughout the state of Pennsylvania. The outputs from this application are GIS mapping and summary reports to manage the 2- and 3-year maintenance spray cycles in each county.

In the past, this roadside vegetation management function was exclusively in a paper media. Consequently, the district roadside specialists developed maintenance spray maps and summary reports manually. Now, the RoSA application produces the maps and reports while handling various spraying operations (tank mix, injection, and end result) and providing additional layers of information (water features, guide rail, government properties, and boundaries, etc.) for managing the roadside integrated vegetation management (IVM) program. RoSA provides a centralized database for the maintenance and operations of the roadside IVM program.

RoSA is a web-based spatial application built using Microsoft's .NET development technology. This was the first application built by PennDOT's GIS Division using this new technology.

INTRODUCTION

Pennsylvania has a favorable climate for growing vegetation along the roadside. Consequently, an integrated vegetation management (IVM) program is an essential part of every county's budget and maintenance operations. And roadside spray applications are important components of the department's IVM program.

There are three main spray programs, 67 counties, and 40,000 mi of road under the department's administration. Over 3,000 records are created annually controlling vegetation along the state roadways. These records are retained by the county office, district office, and contractor applicators. The daily records are used for invoice payment, contract administration, and regulatory requirements.

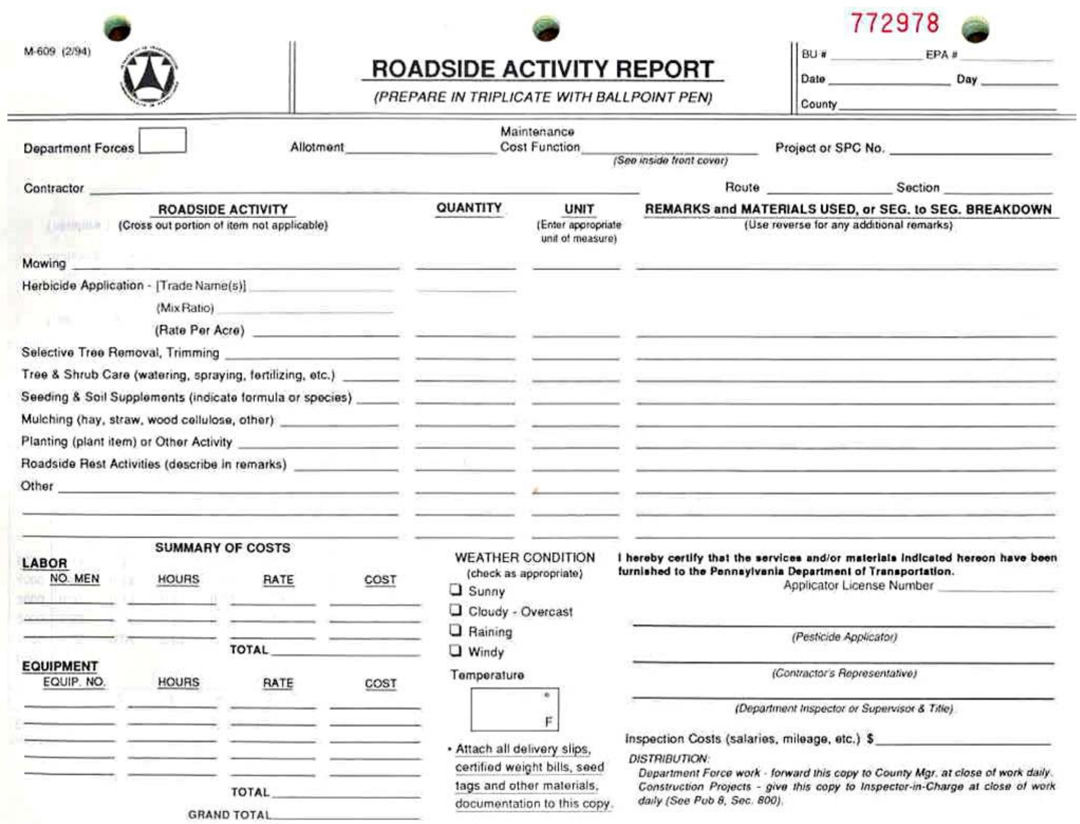
The planning, coordinating, and documenting of roadside spraying has been a part of the department's operating standard for many years. Annually, each county organizes the daily records by cost function and files the paperwork. Retrieving data from previous years involves a trip to the file cabinet and searching through the documentation to find the necessary information. This paper describes the transition from a paper filing system to a geographic information system (GIS)–database system. The new system is called RoSA (Roadside Spraying Application).

HISTORY

Each year a planning map is prepared for each spray program before the start of the season. The maps are posted in each county and used to direct the work during the season. Roads are marked on a completion map as they are sprayed. The completion map is compared to the planning map to determine roads that still need sprayed. The number of hours worked and acres completed are also tracked and compared to planning goals and estimates. The mapping and data summaries are done manually. Each spray program is assigned a different color code as designated in the department's maintenance manual (*1*). The daily spray record for each county is recorded on a roadside activity report called an M-609 form (Figure 1). This document records daily roadside activities of maintenance programs and construction projects.

Recent Developments Prior to RoSA

Recent spray contracts have incorporated several variations from the hourly contracts and acre production standards. End-result spray programs were included in a few contracts due to limited available personnel and results. Contractors are responsible for a given result over the course of the spray season. For example, the contractors are required to keep vegetation clear of sign posts and guide rail and bridge abutments throughout the growing season.


772978
M-609 (2/94)
ROADSIDE ACTIVITY REPORT
(PREPARE IN TRIPLICATE WITH BALLPOINT PEN)
BU # ______ EPA # ______
Date ______ Day ______
County ______
Department Forces [ ] Allotment ______ Maintenance Cost Function ______ (See inside front cover) Project or SPC No. ______
Contractor ______ Route ______ Section ______

ROADSIDE ACTIVITY (Cross out portion of item not applicable)	QUANTITY	UNIT (Enter appropriate unit of measure)	REMARKS and MATERIALS USED, or SEG. to SEG. BREAKDOWN (Use reverse for any additional remarks)
Mowing			
Herbicide Application - [Trade Name(s)]			
(Mix Ratio)			
(Rate Per Acre)			
Selective Tree Removal, Trimming			
Tree & Shrub Care (watering, spraying, fertilizing, etc.)			
Seeding & Soil Supplements (indicate formula or species)			
Mulching (hay, straw, wood cellulose, other)			
Planting (plant item) or Other Activity			
Roadside Rest Activities (describe in remarks)			
Other			

SUMMARY OF COSTS

LABOR

NO. MEN	HOURS	RATE	COST
		TOTAL	

EQUIPMENT

EQUIP. NO.	HOURS	RATE	COST
		TOTAL	
		GRAND TOTAL	

WEATHER CONDITION (check as appropriate)
☐ Sunny
☐ Cloudy - Overcast
☐ Raining
☐ Windy
Temperature ° F
• Attach all delivery slips, certified weight bills, seed tags and other materials, documentation to this copy.

I hereby certify that the services and/or materials indicated hereon have been furnished to the Pennsylvania Department of Transportation.
Applicator License Number ______
(Pesticide Applicator)
(Contractor's Representative)
(Department Inspector or Supervisor & Title)
Inspection Costs (salaries, mileage, etc.) $ ______
DISTRIBUTION:
Department Force work - forward this copy to County Mgr. at close of work daily.
Construction Projects - give this copy to Inspector-in-Charge at close of work daily (See Pub 8, Sec. 800).

FIGURE 1 Roadside Activity Report (M-609).

Several districts have started using injection spray systems instead of the single-tank mixes. Injection systems save money by reducing herbicide usage to only areas that need it. Areas maintained as bare ground such as in the front of guide rails and around signposts are treated with pre-emergent herbicides on 1-, 2-, or 3-year maintenance cycles. A foliar intake herbicide (e.g., Roundup®) is injected into the pre-emergence spray mix when vegetation is present but not needed when there is no vegetation present.

The contractors are paid through the financial system but no system captures and stores the herbicide information required by the Pennsylvania Department of Agriculture (PDA). A paper file must be retained for the last 3 years of spray data for possible PDA review. Also, several districts and counties started to utilize the mapping capabilities of our GIS system over the last 5 years. They had to manually summarize daily spray records into a spreadsheet and forward the data to their respective GIS specialists for maps. RoSA was created to combine the needs for record retention and the capabilities of the department's GIS system.

System Development

The consultants, GIS personnel, and district roadside specialists met to discuss system development after the concept was approved. Data input was determined to be the biggest concern at the development meeting. Data entry needs to be accurate and consistent. Data entry is also very time consuming. The roadside activity report (Figure 1) was familiar to individuals involved in roadside activities and was decided to be the basis for data entry. Other items of importance during the initial development were system users, access security, essential data elements, requested reports, and mapping features.

The main navigation screen for data entry (Figure 2) grays out each section as it is completed. The main data entry screen is the first screen for any new record requiring the date, weather information, contract information and maintenance activity. The spray record is approved only after all the sections are completed (Figure 3). Once a record is approved, only the person who approved the record can change it. Record approval controls record integrity and security.

The initial startup of the system required entering information for the numerous drop-down menus in the daily spray record screens. Drop-down menus provide standard data elements for consistent and uniform spray records. Herbicides, applicators, contracts, and inspectors are several examples of information provided in drop-down menus.

The first year's system development focused on handling spray applications having hourly contracts and tank mixes. The system development for the second year focused on handling various types of spray applications (tank mix, injection, and end result) and providing user-friendly report formats (PDF, spreadsheet, and text, etc.).

MAINTENANCE USER BENEFITS

The RoSA system provides the users the ability to search records, create maps, and run summary reports. County personnel have been using the mapping feature to quickly visualize the work completed and direct the work to the remaining areas. The district administrators are tracking their material use and estimating usage for the upcoming spray season. Central office can view the work from around the state on one central database.

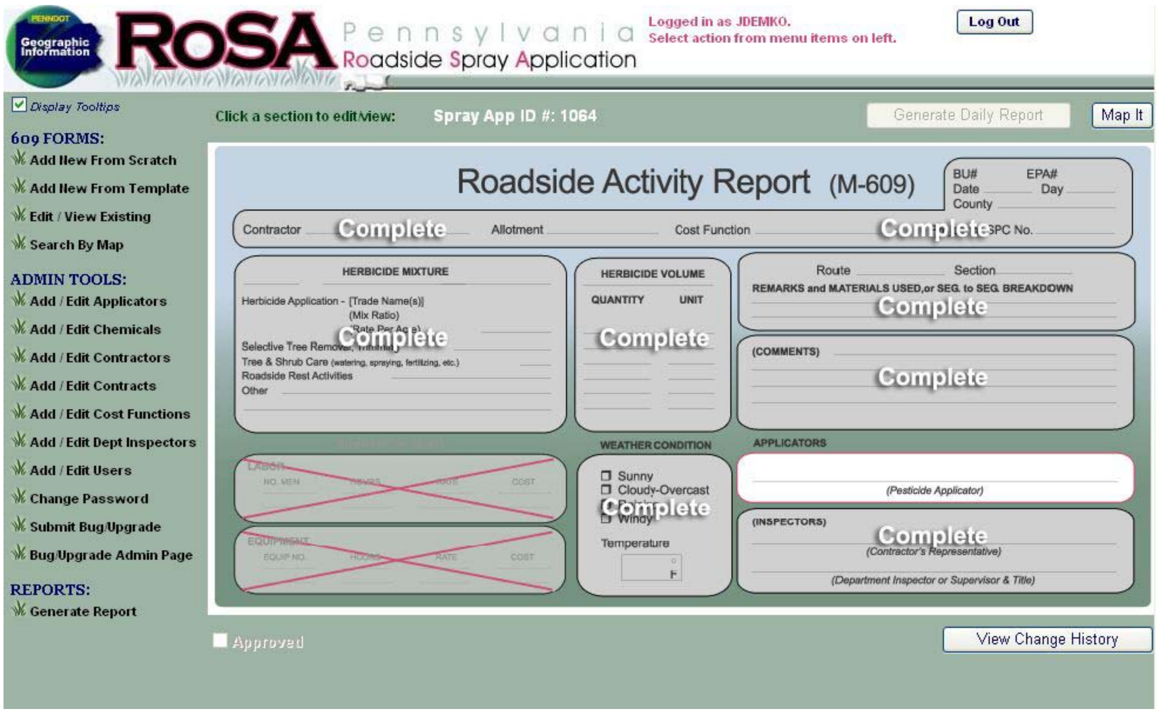


FIGURE 2 Main data entry navigation screen.

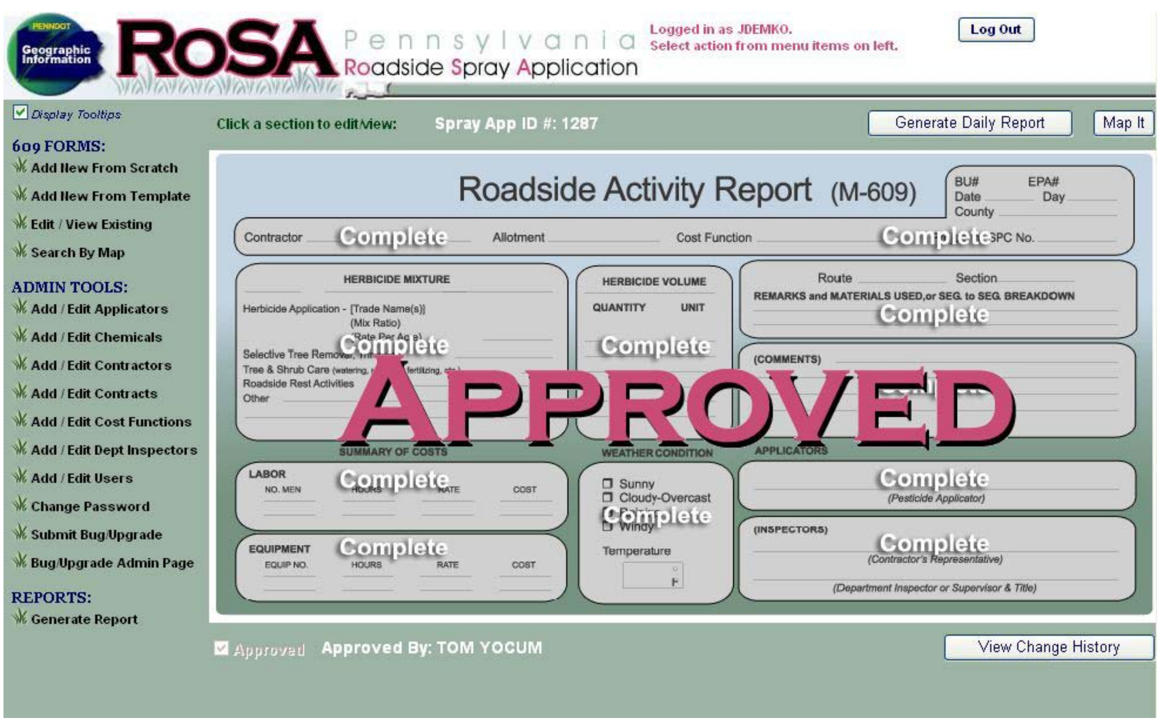


FIGURE 3 Completed–approved spray record.

Data Search

A very flexible and powerful data search is possible from the search engine (Figure 4). A user can search by maintenance activity, state route, date, county, contractor, chemical, applicator, and any other data item included in the daily record. The results of a search can be displayed on the screen (Figure 5) or shown on a map.

Mapping

A resulting map query (Figure 6) will not only show the results of any search but will also include any GIS data layers checked in the map legend such as water features, guide rail, and municipality boundaries. The interactive map can be resized to zoom in or out, measure distances, and exported into a GIS data file. The screen cursor can be placed on any state route to show the road segment and state route number. The screen cursor can also pick out the mapped maintenance activity to show the specific daily record with the spray information on any given road segment.

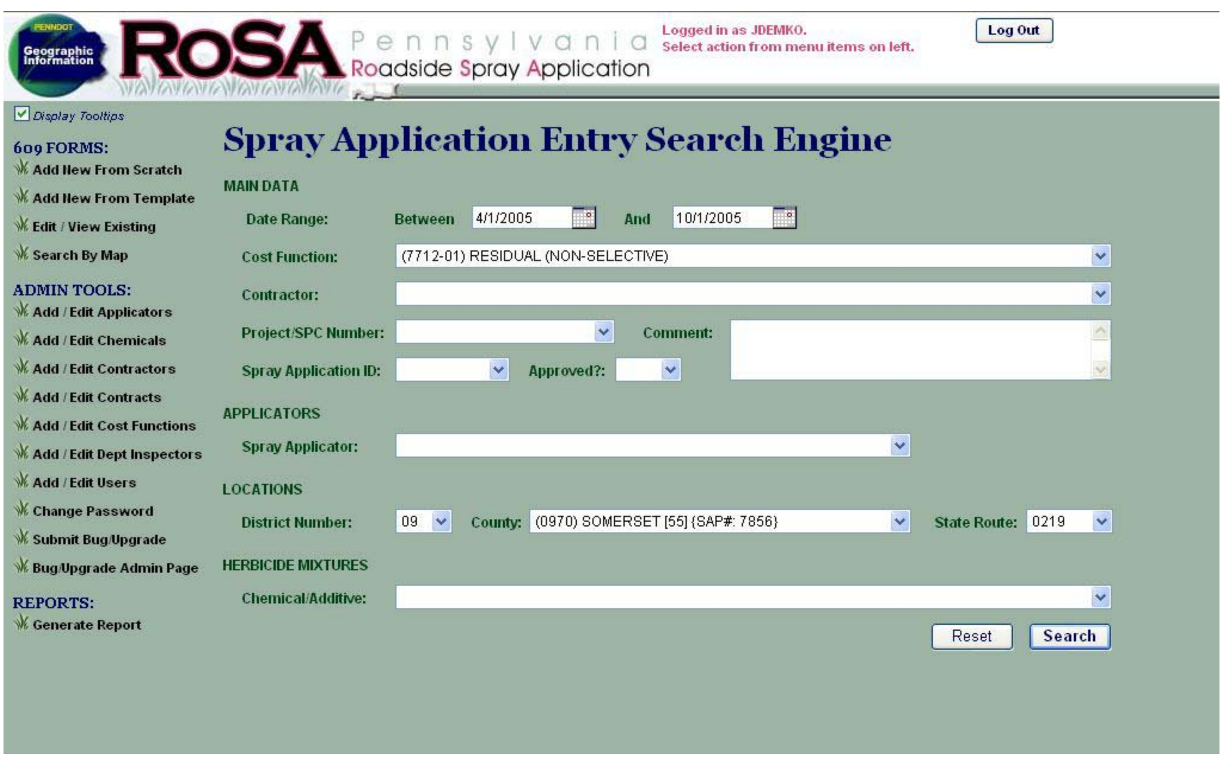


FIGURE 4 Data search engine screen.

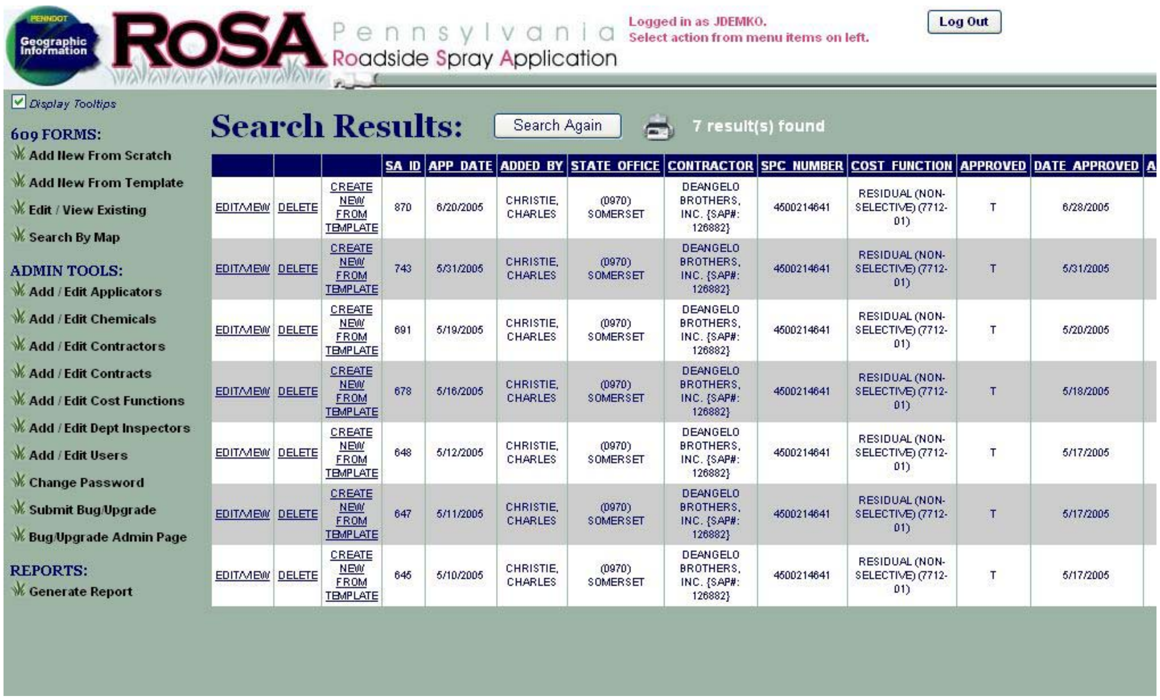


FIGURE 5 Data search results.

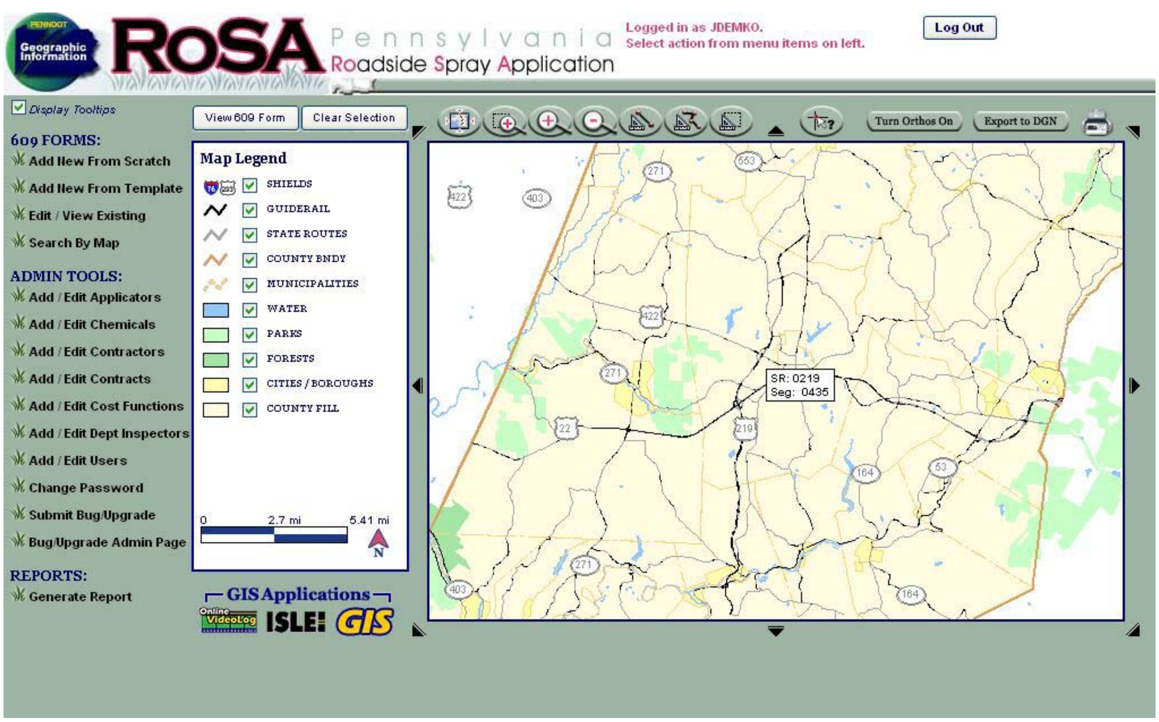


FIGURE 6 Map query result.

Reporting

The reporting engine (Figure 7) can summarize data using numerous criteria similar to the data search engine. The three types of reports in use are chemical usage, contract hours, and production–cost (Figure 8). Each report can be created into various document types including PDF, Excel, Rich Text, Word for Windows, and Crystal Reports for use outside of the RoSA application.

ADMINISTRATION

Each RoSA user is given a set of permissions to perform various functions in the user account administration screen (Figure 9). Most users are given permission to add and edit spray data and generate maps and reports. A limited number of users are given permission to approve spray application records for security and data integrity. The remaining eight functions are restricted to the system administrator, developer, and district administrators. These restricted activities involve handling information on applicators, chemicals, contracts, inspectors, users, activities and record deletion.

RoSA users have the ability to submit problems and suggest improvements for review by the system developer and central office administrator. This list of user feedback is used to plan future enhancements and correct any current problems. Each system user has access to their area of responsibility. A county user has access to their county spray information and a district user has access to the counties in their district.

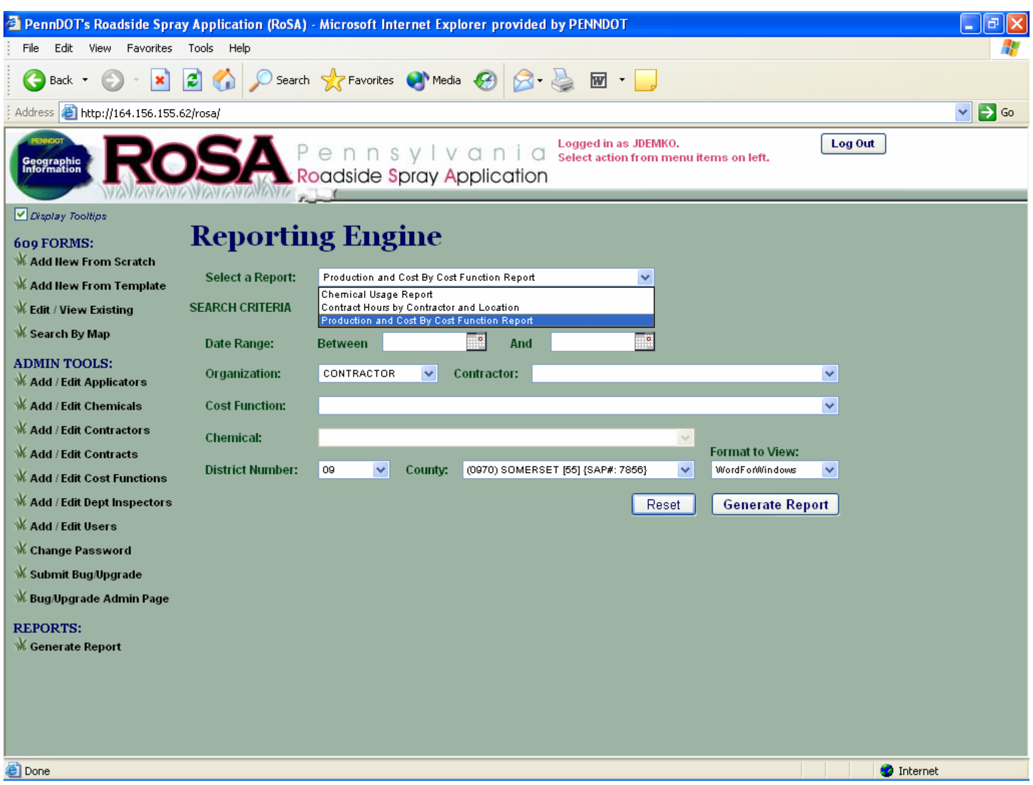


FIGURE 7 Report engine screen.

Production And Cost By Cost Function

All Records

0 *(Unapproved Spray Application Entries Not Included)*

COST FUNCTION	COUNTY	AMOUNT	UNITS	HOURS	COST
{7711-03} P.G.R.`S (PLANT GROWTH REGULATORS)					
District 09					
	(0970) SOMERSET	4.00		8.00	$607.12
		4.00	**Acre(s)**	**8.00**	**$607.12**
		4.00	**Acre(s)**	**8.00**	**$607.12**
{7712-01} RESIDUAL (NON-SELECTIVE)					
District 09					
	(0970) SOMERSET	313.00		528.00	$49,118.52
		313.00	**Acre(s)**	**528.00**	**$49,118.52**
		313.00	**Acre(s)**	**528.00**	**$49,118.52**
{7713-01} SELECTIVE BROADLEAF WEED AND BRUSH CONTROL					
District 09					
	(0970) SOMERSET	508.00		347.50	$34,442.06
		508.00	**Acre(s)**	**347.50**	**$34,442.06**
		508.00	**Acre(s)**	**347.50**	**$34,442.06**
{7714-01} SELECTIVE BRUSH, TREE GROWTH AND SIDE TRIMMING CONTROL					
District 09					
	(0970) SOMERSET	600.00		379.50	$36,073.24
		600.00	**Acre(s)**	**379.50**	**$36,073.24**
		600.00	**Acre(s)**	**379.50**	**$36,073.24**

FIGURE 8 Production–cost report.

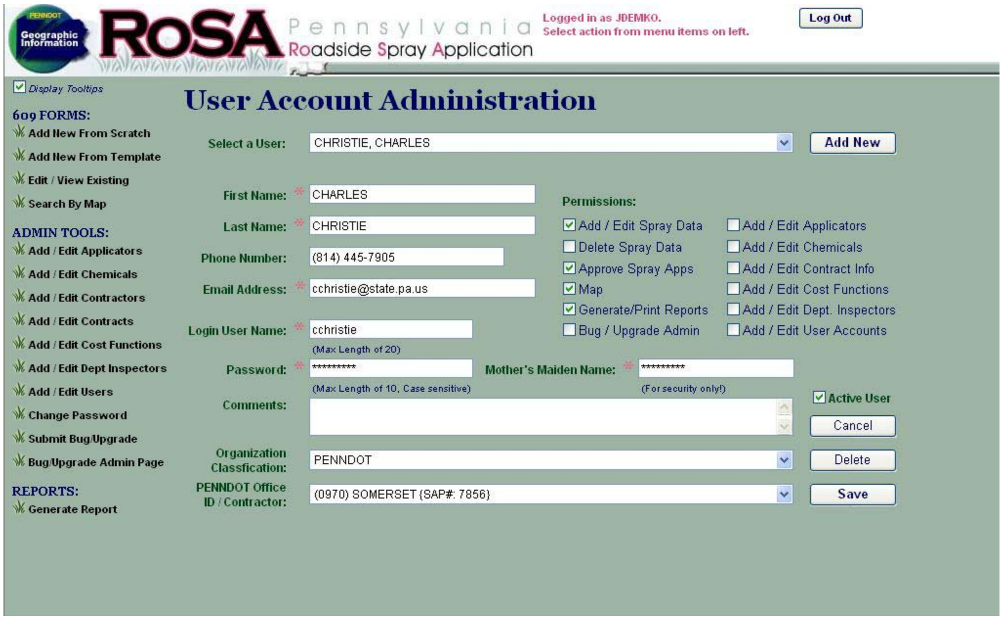


FIGURE 9 User administration screen.

CONCLUSION

RoSA has completed two spray seasons of use. The districts and counties find RoSA very useful. Enhancements after the first year allowed for various spray applications and various formats of reports. Accurate data entry continues to be essential in providing a useful system.

RoSA fills a roadside maintenance need to track and retrieve roadside spraying information in a quick and useful format. The resulting database and mapping functions with GIS layering has brought a new planning and management tool to the roadside users of Pennsylvania Department of Transportation. With RoSA spray information is at the district roadside specialists' fingertips instead of in a distant file cabinet.

A planning component is the focus of future enhancements for the RoSA system. The addition of the planning component would give the system all the capabilities of the manual process. The maintenance personnel, who have used RoSA, see useful applications of the system to other maintenance activities in addition to roadside spray applications. Showing planned activities on a map would allow many maintenance personnel at the county level to visualize the progress of work through the year in addition to the standard paper files and reports.

Another system enhancement that many current users want is the ability to include tree removal activities into the system. Generating maps of planned cutting areas would to help contractors locate and plan tree work and assist department field operations. Areas needing tree cutting could be flagged in the system throughout the year and printed out when the work is schedule. The ability to handle tree removal activities is another important part of the next system enhancement.

REFERENCE

1. *Maintenance Manual*, Publication 23, Chapter 13: Roadside Management, Section 13.4 Herbicide Vegetation Control. Pennsylvania Department of Transportation, Harrisburg, 2004, pp. 13-7–13-13.

PART 3: ROADSIDE MAINTENANCE

MS4 Permit Compliance
Maintenance Operations Activities

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KELLIE THOM
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This paper discusses the practical approach that the Minnesota Department of Transportation (Mn/DOT) Metro District has taken to implement the Environmental Protection Agency's National Pollutant Discharge Elimination System (NPDES) Phase II Municipal Separate Storm Sewer Systems permit compliance activities for maintenance operations. To comply with these worthwhile environmental goals within a limited operations budget, technology, effective communications, shared goals and coordinated planning, effective education efforts, and rigorous project planning have been critical to a successful program.

The best management practices involving maintenance operations include ongoing inspection and maintenance of drainage infrastructure, materials management, and compliance with correct operation processes within such areas as street sweeping and tunnel washing. In each of these areas, Mn/DOT is expected to perform to a certain level and to document its activities.

Global positioning satellite and geographic information systems (GIS) technology have been used to identify in place drainage infrastructure and to document work that needed—repairs or periodic cleaning. Effective communication between maintenance operations personnel and water resources personnel allows for clear understanding of resources available, shared inventory and management data, establishing GIS mapping to determine drainage infrastructure project priorities based on type of system, work needed, and proximity to special waters, as well as documentation of completed projects.

While many agencies have taken actions to become compliant with the NPDES requirements, Metro District's efforts are a powerful example of how to be compliant with limited resources and reap other environmental and operational benefits.

INTRODUCTION: ENVIRONMENTAL REQUIREMENTS

In 1972, the United States passed the Federal Water Pollution Control Act which has since been renamed the Clean Water Act. The bill was created to reduce pollution and improve water quality in the United States. Under this bill, a national program called National Pollution Discharge Elimination System (NPDES) was created to regulate point source pollution to confined surface waters and underground waters (i.e., waters of the state). In 1990, Phase I of the NPDES program was implemented. This required agencies that manage large Municipal Separate Storm Sewer Systems (MS4s) (100,000 people or greater) to create a storm water program to aid in the control and elimination of pollution from their point sources. In 1999, Phase II of this program began which targeted smaller MS4s as designated by the Bureau of Census to have a population greater than 50,000 and less than 100,000 (*1*).

Phase II of the NPDES permit program has six minimum control measures that, when implemented, are stated to have the capability of significantly reducing point source pollution in relation to storm water discharge. The six control measures are (*2*)

1. Public education and outreach,
2. Public participation–involvement,
3. Illicit discharge detection and elimination,
4. Construction site runoff control,
5. Post construction runoff control, and
6. Pollution prevention–good housekeeping.

For each of the six minimum control measures the MS4 must create best management practices (BMPs) and measurable goals to satisfy them.

MINNESOTA DEPARTMENT OF TRANSPORTATION METRO BEST MANAGEMENT PRACTICES

The Minnesota Department of Transportation (Mn/DOT) Metro District has been designated a small MS4 under Phase II. Mn/DOT Metro District, commonly referred to as Metro, is composed of eight counties, which surround and include the cities of Minneapolis and St. Paul. Seven of the eight counties in Metro are urban, including 114 local government Phase II MS4s and two Phase I MS4s (Minneapolis and St. Paul). Metro has 1,500 employees, 18 truck stations/sub-areas, 4,800 lane miles of Interstate and trunk highways, and 40,000 acres of right-of-way.

Metro applied for the NPDES Phase II MS4 permit from the Minnesota Pollution Control Agency, the state's governing agency, through the creation of a Storm Water Pollution Prevention Program (SWPPP). The SWPPP includes 25 BMPs with measurable goals to address all of the six minimum control measures. The BMPs require involvement from several functional offices within Metro, however the bulk of the BMPs are for Water Resources Engineering (WRE) and Metro Maintenance Operations. This paper will focus on the Metro Maintenance BMPs and the problems, solutions, and improvements associated with them.

Metro Maintenance Operations consists of 548 employees, 638 pieces of mobile equipment, 18 sub-areas, and an annual operating budget of $42,800,000. Each sub-area is a geographic work area that has assigned personnel (including a supervisor) and equipment housed in a maintenance facility for the purpose of maintaining the roadway infrastructure in their and surrounding areas.

Metro Maintenance has five of the 25 BMPs:

1. Non-storm water discharges (BMP 10),
2. Routine maintenance activities (BMP 19),
3. Vegetation management program (BMP 22),
4. Street sweeping program (BMP 24), and
5. Anti-icing/deicing program (BMP 25).

Each BMP has one or more measurable goals and includes an implementation schedule.

Non-storm water discharges, street sweeping, and anti-icing/deicing measurable goals have been met by using processes that have been evaluated by consultants on their ability to reduce pollution originating from a single point, i.e., point source pollution (*3*). The vegetation management program BMP measurable goal has also been met and exceeded it through the use of technology. The routine maintenance BMP measurable goals have not all been met.

Non-Storm Water Discharges

Non-storm water discharges, BMP 10, is a new BMP created to identify non-storm water discharges from maintenance activities which have significant potential to impact storm water. Those impacts are then to be addressed through source removal–reduction, implementation of BMPs, and developing appropriate standard operating procedures for these activities. During the permit processes for Metro there were two non-storm water discharges identified: tunnel cleaning and outdoor vehicle washing. Outdoor vehicle washing has been addressed in the facility storm water plan and employee training. As for tunnel cleaning, Metro has seven tunnels in the district, all of which drain to significant surface waters through city and Mn/DOT storm sewer systems. The measurable goals of this BMP include the following.

1. Evaluate tunnel-cleaning operations and determine trigger mechanisms to move to measurable Goal 2 by 2005.
2. If tunnel-cleaning operations are determined to require BMPs, then develop a standard operating procedure (SOP) and corresponding BMPs to reduce pollution from tunnel cleaning by 2006.
3. Evaluate other non-storm water discharges as they are identified through illicit discharge and outfall inspections (BMP 6).

The problem associated with this BMP was how to determine if Metro's tunnel-cleaning methods were affecting the environment. To solve this problem a consultant was hired to observe their cleaning methods and determine if the environment was at risk. Due to the low ratio of cleanser to water it was decided that the current procedure was acceptable. The procedure was then standardized with corresponding BMPs.

Street Sweeping

Street sweeping, BMP 24, was an existing BMP prior to Phase II of the NPDES permit and its main objective was to ensure that Metro District was aware of current technologies for street sweeping, the benefits of performing routine street sweeping, and the importance of tracking and reporting street sweeping activities. As stated above Metro, has 3,950 lane miles of truck highways and Interstates, all of which have to be cleaned routinely. The measurable goal of this BMP is to perform street sweeping to remove salt, sand, debris, and other potential contaminants from roadways annually in the spring.

The problems with street sweeping were how to ensure the sweepings were not full of contaminants and where to dispose of the sweepings. It was determined that sweepings should be screened to separate out the sand and aggregates from other materials (some of which is recycled). The sweepings were routinely tested to determine if and where they could be reused and the results have shown that the sand can be used for roadway fill on Mn/DOT property. The sweepings will be tested every 3 years.

Anti-Icing–Deicing for Snow and Ice Removal Operations

Anti-icing–deicing, BMP 25, is an existing BMP that ensures that Metro is aware of current technologies for anti-icing–deicing within snow and ice removal operations, is working to reduce harmful amounts of chemicals and salt used, and employs good housekeeping practices related to anti-icing–deicing operations. Due to snow and ice on the roadways during the winter season in Minnesota and the large amount of vehicles traveling at all times within the metropolitan area, Mn/DOT works diligently to ensure safe travel in winter conditions. To accomplish this, Metro Maintenance uses the most efficient chemicals and technology possible. The measurable goals for this BMP are

1. To develop tracking–reporting mechanism for materials applied to roads for inclusion in the annual report by the end of 2004;
2. To analyze current and available measures, equipment, and chemicals annually; and
3. To substitute high-impact measures for low-impact measures as appropriate.

The challenge associated with this BMP was over-application. In the urgency to deice roads, over application can occur due to non-calibrated application systems and operator error. There were also corrosive problems associated with chemical–salt mixtures.

The solution to the above-mentioned problems was obtained through education, research, and experimentation. To avoid over-application of salt, a Dickey John calibrator controller was installed and calibrated on all plow–deicing trucks. This allows operators, who are increasingly better educated, to control the amount of chemical–salt applied to the roadway. To reduce the corrosive potential from anti-icing, various anti-icing agents are in use and others are routinely tested.

Vegetation Management

Vegetation management, BMP 22, is another existing BMP. This BMP was created to minimize Metro's use of herbicides and fertilizers and to properly apply these products when used, as well as incorporate native vegetation and biological agents along roadside shoulders and medians for ease of maintenance and soil stabilization. The measurable goal for this BMP is to continue to implement the vegetation management program on a continual basis.

Problems associated with this BMP were and are the continual search for low-cost and highly effective means of managing vegetation. The solution to this problem is research of new techniques, chemicals, and biological methods to reduce invasive vegetative species and environmental impacts. Currently, the vegetation management program is using Purple Loosestrife and Leafy Spurge Flea beetles to control invasive species in over 100 sites recorded with Global Positioning Satellite (GPS) units. The program has also been researching new technologically advanced machinery for herbicide application to reduce over applications.

Routine Maintenance Activities

Routine maintenance activities, BMP 19, is a new BMP. This BMP was created for Metro Maintenance operations to schedule and perform routine maintenance of outfalls, sediment basins and ponds, and structural pollution control devices (SPCDs). The measurable goals associated with this BMP are

1. To formalize a routine maintenance schedule and review and revise it as appropriate by 2005 and annually thereafter;
2. To amend the maintenance reporting–tracking database annually;
3. To train maintenance staff on storm water awareness and BMP operation and maintenance annually; and
4. To investigate revising the maintenance manual to include a storm water quality management chapter or using Mn/DOT Intranet to post SOPs, policies, and memos for easy accessibility and up-to-date information by 2006.

The problems associated with this BMP were that Metro WRE, not maintenance, was charged with finding the locations and conditions of hydraulic structures, SPCDs, and ponds. Beyond finding the locations and conditions of these drainage items, issues of concern included: how to get to those areas which needed maintenance, how to schedule maintenance activities and what to base that schedule on, what type of activities to focus on, how to track maintenance activities, and how to train staff.

Solutions for these problems took a joint partnership between Metro WRE and Maintenance. The two functional areas worked closely together since many of WRE BMPs intertwine with this BMP. Throughout training workshops, data mining, and product delivery this partnership ensured that both sides worked together to achieve their BMP goals.

Process

To make the process efficient, a decision was made that cleaning would be the first maintenance activity to be scheduled. In order to organize all the different hydraulic structures to be cleaned, three hydraulic groups were created. Hydraulic Group 1 consisted of hydraulic structures such as catch basins, manholes, aprons, and pipes. Hydraulic Group 2 consisted of SPCDs. Hydraulic Group 3 consisted of ponds.

Group 1: Hydraulic Structures Since Metro WRE was already collecting GPS location and condition information on hydraulic structures within Metro, it was decided that they would provide location information on hydraulic structures where cleaning was needed. This was accomplished through querying the Mn/DOT hydraulic database and importing that information into a geographic information system (GIS) dataset. The information was then broken down into Priority 1, Priority 2, and Priority 3 datasets. Priority 1 stood for those structures in need of cleaning which were within a mile of any protected waters. Priority 2 stood for those structures that needed cleaning which were within 1 mi of any total maximum daily load waters. Priority 3 was the remainder of the structures that needed to be cleaned.

While this GPS location information could be plotted on a map, the problem arose of how to get to the Priority 1, 2, or 3 project sites in the field. Uploading the information on the map to GPS units solved this problem by allowing the users to navigate to the project locations. With the priority datasets loaded onto the GPS units, a select group of maintenance personnel (locators) were chosen to receive MS4 GPS training. While most of these individuals had training on how to use a GPS unit for collecting data, they had not received training on how to use one for navigation purposes.

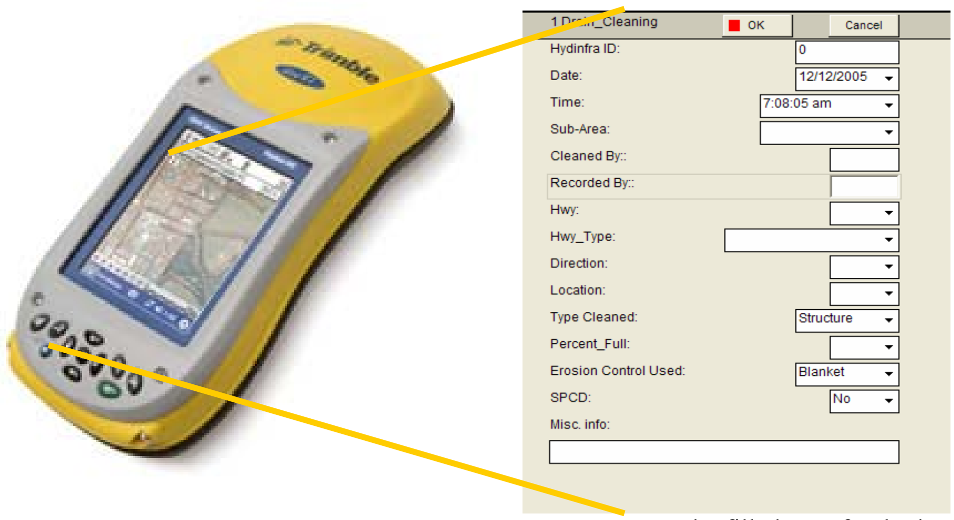
The 1-day training workshop consisted of explaining data collection, navigation with the GPS unit, and the type of data with which they were working. After covering the processes of collecting and navigating with the GPS units, an explanation was given regarding what they were looking for and why Metro needed this done as compared to numerous other field work requests. Once everyone understood the basis for the extra work, they learned the process of how the work was to be done. Each of these locators was then assigned one quarter of the Metro to carry out these duties. First, each sub-area supervisor would call their locator to locate all their Priority 1 sites to be cleaned in their area (if they had none, Priority 2 projects were located). The locator would then mark them with lath. Once they were marked, the sub-area personnel would then clean or repair the structures and notify the locator when each project was complete. The locator would then go back to the project's location and record the needed information. Once the Priority 1 locations were completed within a sub-area, then the Priority 2 locations would follow. In order for the data collection to be efficient and uniform, a form was loaded onto the GPS units (a data dictionary) which the locators would fill out each time they visited a cleaned or repaired structure. The form consists of the following:

- Identification number (provided by WRE),
- Date,
- Time,
- Sub-area,
- Cleaned by,
- Recorded by,
- Highway,
- Highway type,
- Direction,
- Location,
- Type cleaned,
- Percent full,
- Erosion control used,
- SPCD, and
- Miscellaneous information.

These forms are electronically downloaded weekly at the district office. They are used for tracking cleaning projects' completion and updating the Mn/DOT hydraulic database which is linked through the identification number of the hydraulic structure (Figure 1).

Group 2: Special Pollution Control Devices Metro WRE located grit chambers and other SPCDs through plan sheet inventories and communication with WRE designers. While efforts to complete the inventory are ongoing, the SPCDs inventoried were inspected by WRE, maintenance, and environmental services personnel. In the field, the amount of sediment was determined by measuring from the top of sediment in the chamber to the top of the grit chamber and comparing that measurement to the designed depth. Upon inspection, most of the grit chambers needed to be cleaned. The cleaning of the grit chambers was performed by maintenance.

Group 3: Ponds Metro WRE is currently locating and identifying all ponds within the Metro area. A dataset was initially formed through the use of GIS and aerial photography. After the initial dataset was formed, WRE again joined forces with maintenance to use their knowledge, via a field visit, to aid in filtering out the ponds within Mn/DOT right-of-way and maintained by Metro maintenance. At each visit an explanation was given regarding the need to collect this information, what it would be used for, and how it affected maintenance. Once all 18



GPS handheld

Form to be filled out after hydraulic structure has been cleaned. The completed forms are downloaded weekly.

FIGURE 1 GPS data form.

sub-areas were visited, WRE updated their data set and went through construction plan sheets to find all possible information about individual ponds. This information was incorporated into the final data set, which will be assessed by designers to determine cleaning recommendations for each pond based on original design criteria. Once a recommendation has been received by maintenance, they will determine if the project is to be completed with internal staff or done under contract. Some of the factors used in this determination are size and location of pond, special equipment needed, vegetation restoration, pond lining, if any, proximity to waters of the state, and workload or other priorities.

Since these activities are cyclical, after completion of all cleaning activities WRE will update all datasets and begin the process of creating new datasets. The new datasets will be given to maintenance as project lists for their crews to work on during the next spring, summer, or fall. Hydraulic structures, pond and SPCD’s which were cleaned this year will be monitored each year to see when re-cleaning needs to occur. This will allow a schedule to emerge on the frequency of cleaning needed which will in turn allow more rigorous work planning.

Training for Routine Maintenance Activities

During the implementation of the cleaning schedules, training workshops were given to the sub-area supervisors. The supervisors learned about the MS4 permit and how it affected them. They were each given an informational packet which included an agenda, copy of the MS4 general permit, definitions of special waters of the state, Priority 1, 2, and 3 cleaning projects, list of watershed districts within Metro, photo examples of good and poor project work, an erosion and sediment control pocketbook guide, a list of erosion control contract vendors, plan sheets showing ditch typical sections, the locator for their sub-area, and a data flow diagram. The training was very well received.

Tracking of Routine Maintenance Activities

Tracking of projects and data for each BMP is required for the MS4 permit. This requirement has been achieved through the use of an ArcIMS site. ArcIMS is a web-based tool that allows users to access geographical information such as the datasets mentioned above. Data that is being produced for meeting BMP requirements–goals is uploaded to the ArcIMS site that can be seen by those who need to verify and use the data. Currently maintenance and WRE each have their own ArcIMS sites to display data specific to their own MS4 BMPs. See Figure 2 for an example of the Maintenance ArcIMS site.

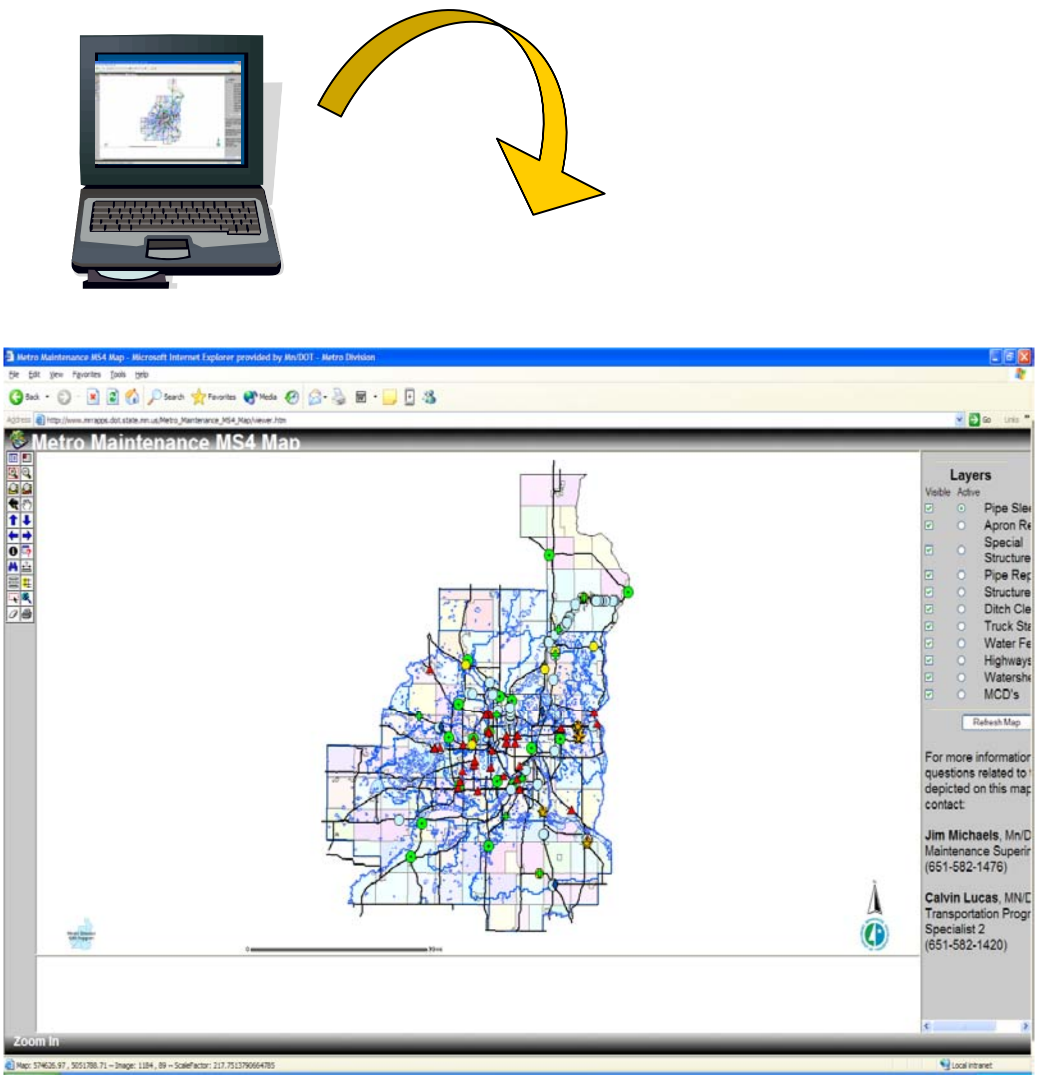


FIGURE 2 Maintenance ArcIMS site (www.mrrapps.dot.state.mn.us/Metro_Maintenance_MS4_Map/viewer.htm).

LESSONS LEARNED

While all of the BMPs have not yet been fully met, there have been lessons learned through the BMP creation and implementation process. As stated previously, technology, communication, flexibility, research, and experimentation all have been, and will continue to be, necessary to meet the measurable goals of each BMP.

Technology has been an important implementation tool for BMP 19 (routine maintenance activities) and BMP 22 (vegetation management program). GPS and GIS have allowed tracking work progress and record keeping of completed projects with a minimal workforce. These, and other technologies such as digital recording cameras, have eased the transition from past to the new procedures. The equipment that is used must be designed for field application and user friendly so field personnel do not get frustrated and lose interest in the process.

Communication has been, and will continue to be, a very important element in the implementation process. Much coordination was needed between three different functional areas: maintenance, WRE, and the website administrative group within Metro. Representatives from each of these units met regularly to discuss problems that arose and the possible corrective action or procedure for each. Communication is also important with the field employees. Anyone that is affected by, or is responsible for, MS4 activities that have questions or problems is responded to with answers as soon as possible.

Flexibility has been difficult, but also rewarding. Through training and the awareness of the MS4 permit, standard procedures have changed to meet the new BMP requirements. While these new operational procedures have been implemented and followed for the most part, continued training is needed to ensure that all procedures are followed.

Research and experimentation have been some of the most important tools in meeting and improving all of the BMPs. Through research, low-cost–high-productivity technology, equipment, and tools have been found. This has been important because a limited number of available employees and stagnant or decreasing budgets are, and will be, the operational reality. Experimentation has been equally important in finding the most efficient process for carrying out the BMPs. From data collection methods to type of chemicals used to de-ice roadways, experimentation and research has been, and will continue to be, necessary to implement current and future BMPs.

Each of the above mentioned processes will continue to be updated as environmental rules and regulations change. It is almost certain that all of the BMPs mentioned will be modified, as will the processes used to meet their requirements. The most important lesson learned though the implementation of these BMPs is that modifying current standard operating procedures is necessary. “Out of the box” thinking is a key requirement for anyone going through this process and it also happens to be the most challenging.

ACKNOWLEDGMENTS

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REFERENCES

1. Minnesota Pollution Control Agency, Stormwater Program for Municipal Separate Storm Sewer Systems (MS4), September 2005. www.pca.state.mn.us/water/stormwater/stormwater-ms4.html. Accessed October 2005.
2. Minnesota Pollution Control Agency, Stormwater Program for Municipal Separate Storm Sewer Systems (MS4), September 2005. www.pca.state.mn.us/water/stormwater/stormwater-ms4.html. Accessed October 2005.
3. Water-Technology.net. www.water-technology.net/glossary/point-source-pollution.html. Accessed December 2005.

PART 4

Winter Maintenance

PART 4: WINTER MAINTENANCE

Deployment of Maintenance Decision Support Systems for Winter Operations

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The art and science of road maintenance during adverse winter conditions has long been hampered by a lack of true integration of weather information into operations. Beginning in 1999, FHWA began to study this deficiency with its Surface Transportation Weather Decision Support Requirements (STWDSR) effort. The results clearly showed that road maintenance personnel desire better, more specific weather forecast information, which could improve the productivity and efficiency of winter maintenance practices and ultimately lead to improved mobility and a safer driving environment.

Beginning in 2000, the FHWA convened a team of national laboratories and created a stakeholder group of interested personnel from state departments of transportation (DOTs), private-sector weather service providers and academia. With guidance from the stakeholder community, the laboratories combined state-of-the-art weather forecasting capabilities with computerized winter maintenance rules of practice. This was the genesis of the winter Maintenance Decision Support System (MDSS) prototype. This prototype underwent several development cycles and three seasons of field demonstrations and evaluations—two in Iowa and one in Colorado. By 2004, MDSS technologies were mature enough for interested private-sector companies to begin to incorporate MDSS features into their product lines and begin to provide services to state DOTs. At this point, the FHWA MDSS effort transitioned from prototype enhancement to a focus on technology transfer to both the private sector and the states.

Based on the national MDSS effort, as well as related activities, a group of eight states (led by South Dakota DOT) initiated a pooled-fund study in 2002 to develop and implement an operational version of MDSS for their agencies. The study has focused upon refinement, validation, and wide-scale deployment of sustainable MDSS technology, as demonstrated in a successful operational testing period over the 2004–2005 winter. Based on these complementary efforts, it is clear that the MDSS presents a valid and viable operational strategy, but not without its development and deployment challenges. This paper will detail strategies for the continued evolution of MDSS technologies into the marketplace as well as advancement of the state of the practice of winter maintenance. Details of the pooled-fund MDSS project will be presented as one success story of deployment.

INTRODUCTION

Managing winter maintenance activities is a complex endeavor. Ensuring that the plow blades are ready when the first flakes fall is only a small part of the task. Maintenance managers also must know the regulations about chemical applications and environmental impacts, and be able to analyze and make sense of multiple and often contradictory weather forecasts. Many maintenance managers also face tight budgets. When these factors come together, they test a public agency's skill at meeting the traveling public's high expectations for roads to be kept free of snow and ice. Thus, today's maintenance managers require the ability to efficiently handle multiple tasks and process high volumes of information, or risk getting left behind in the onslaught of winter weather (*1*).

FHWA long recognized the challenges faced by maintenance managers (*2*). With the creation of the Road Weather Management Program in the late 1990s, the FHWA began to work on improving the kinds of information that were available for winter maintenance. At that time, weather forecasts were plentiful, and a few companies issued route-specific forecasts; however, there was no link between the available weather information and the decisions made by maintenance managers about winter road treatments (e.g., the best time to treat roads, and whether salting, plowing, or a combination of approaches is most appropriate). It was this missing link that led to the genesis of the winter Maintenance Decision Support System (MDSS) project (*3*). The MDSS project was collaboration between a diverse stakeholder group consisting of state departments of transportation (DOT) maintenance practitioners, five national laboratories, and the academic and private-sector communities. The MDSS prototype project was funded and directed by the FHWA Road Weather Management Program with significant support from the Intelligent Transportation Systems Joint Program Office.

MDSS OVERVIEW

Figure 1 shows the data flow and major components of the FHWA MDSS prototype. Ten different numerical weather prediction models (top left, Figure 1) provide weather forecast prediction information into a data fusion module called the Road Weather Forecast System (RWFS). The RWFS (top right, Figure 1) also receives surface meteorological observations from National Weather Service and FAA airport sites. The system ingests both atmospheric and pavement data from state DOT Environmental Sensor Stations that are deployed along many roads. Algorithms within the RWFS component then process the information and provide one set of forecast outputs that can be used in the Road Condition and Treatment Module (RCTM).

The RCTM (lower right, Figure 1) contains algorithms that focus on the state of the road surface. These include models for road temperature prediction, snow accumulation, road and bridge frost probability, blowing snow probability, and chemical concentration and dilution. These routines then provide input into the rules of practice algorithm for anti-icing and deicing. The resultant output consists of route-specific forecasts of weather, road conditions, and treatment recommendations. Most of these can be seen in the MDSS graphical user interface (GUI) (lower left, Figure 1).

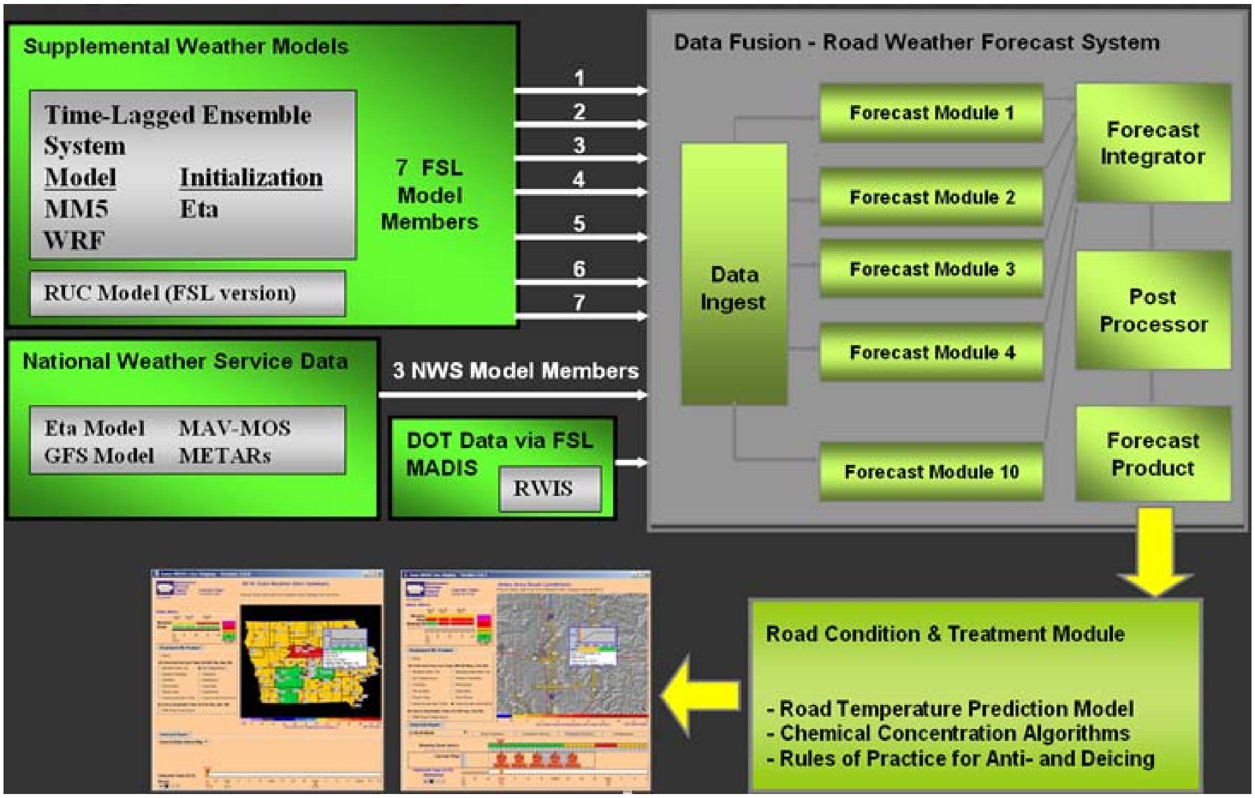

FIGURE 1 MDSS functional structure (data and process flow). Ten different weather models and sources of observations feed into the RWFS. The RWFS integrates and processes each set of data and provides optimized forecast elements to the RCTM. The RCTM contains algorithms for road temperature prediction, chemical concentration, and the rules of practice for anti- and deicing. The resulting forecast information and treatment recommendations flow to the user displays.

The layout of the main GUI of the FHWA MDSS prototype (Figure 2) was approved by a committee of state DOT maintenance practitioners. It was developed so that maintenance personnel would be able to quickly peruse the screen and determine if there were any weather hazards forecast in their area.

The top left portion of the GUI (in Figure 2) contains the alert status window. This window uses easily distinguished color-coded bars to alert users if there are forecast hazards due to weather, deteriorating road conditions, blowing snow, or road frost. The middle left window allows the operator to select different observations or forecasts. These values can be displayed on the main GUI window. The bottom of the GUI provides a time–scale controller to allow for animating forecast data in the main GUI screen. There are also color-coded bars that show which hours specific routes could be affected by road frost or blowing snow. The main display screen provides high-resolution topographical backgrounds along with displayed observed and forecast information.

One innovative module that was developed for the MDSS prototype was called the “what-if” generator (Figure 3). This capability allows an operator to modify the timing, chemical

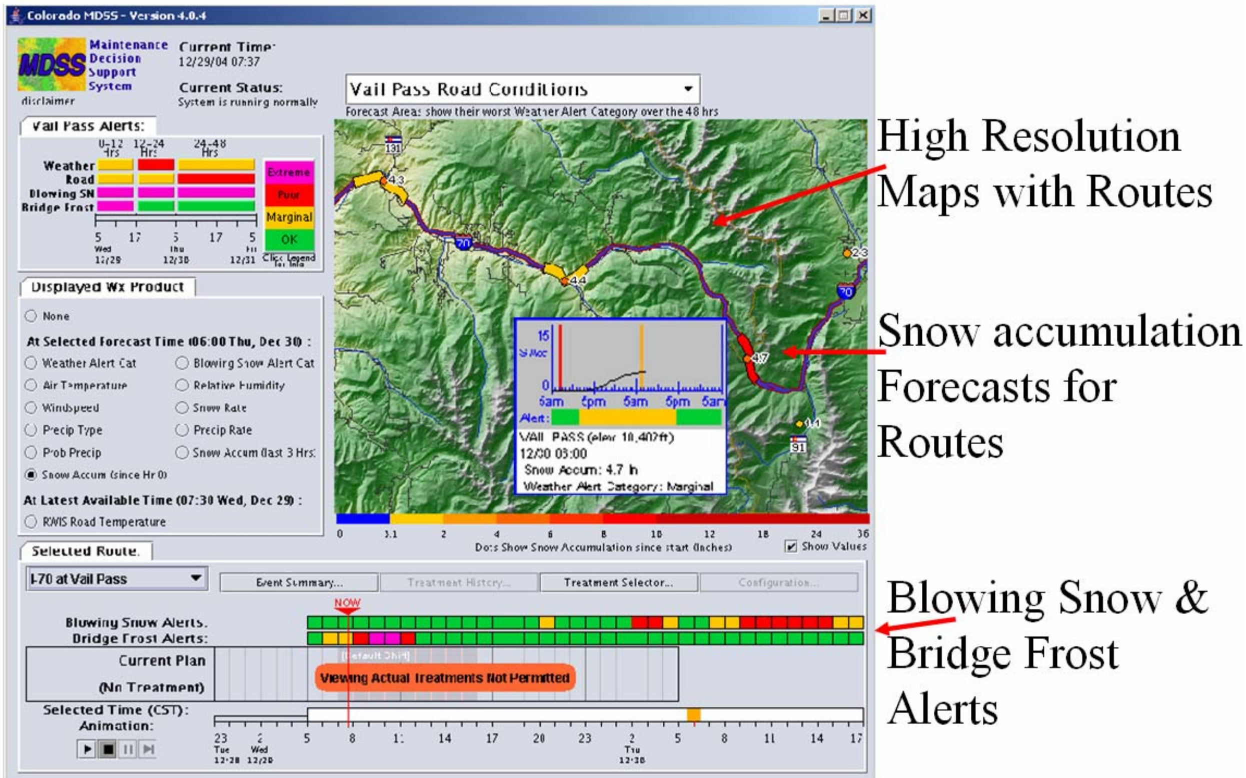

FIGURE 2 MDSS prototype GUI. The GUI consists of several distinct sections that are optimized for the maintenance manager. The alert screen (*top left*) shows color-coded bars representing forecasts of weather and road condition. There are also indicators for blowing snow and bridge frost potential. The weather selection box (*center left*) provides the ability to display many observed and forecast fields. The animation control box (*bottom*) allows the user to change forecast times and to create an animation of forecast parameters. The main display (*top right*) provides high-resolution topographic backgrounds and graphics depicting observed data and forecasts.

type, or application rate on any of the routes to see how the changes might affect the treatments or forecast road condition. In the example shown in Figure 3, the total number of plowing and chemical application passes was decreased (from 4 to 3). In addition the amount of applied chemical was reduced (from 200 to 100 lbs per lane mile). The resulting alternative set of inputs (as shown with a dark blue trace on the graph) shows that snow will begin to accumulate on the route. The green trace shows the snowfall accumulation rate if no treatments were made.

The MDSS is a complex amalgam of computer hardware and algorithms. As such, it is unlikely that many (if any) state DOTs have the expertise or desire to own or operate an entire MDSS. It is more likely that states interested in MDSS capabilities will contract with a private-sector weather service provider so that only display software would need to reside in DOT maintenance facilities. For this reason, numerous private-sector weather service providers have been encouraged to participate and have been engaged in the stakeholder group to develop the MDSS prototype. The intent is to get as many companies involved as possible, and provide to them the prototype software, thereby making deployment as fair and seamless as possible.

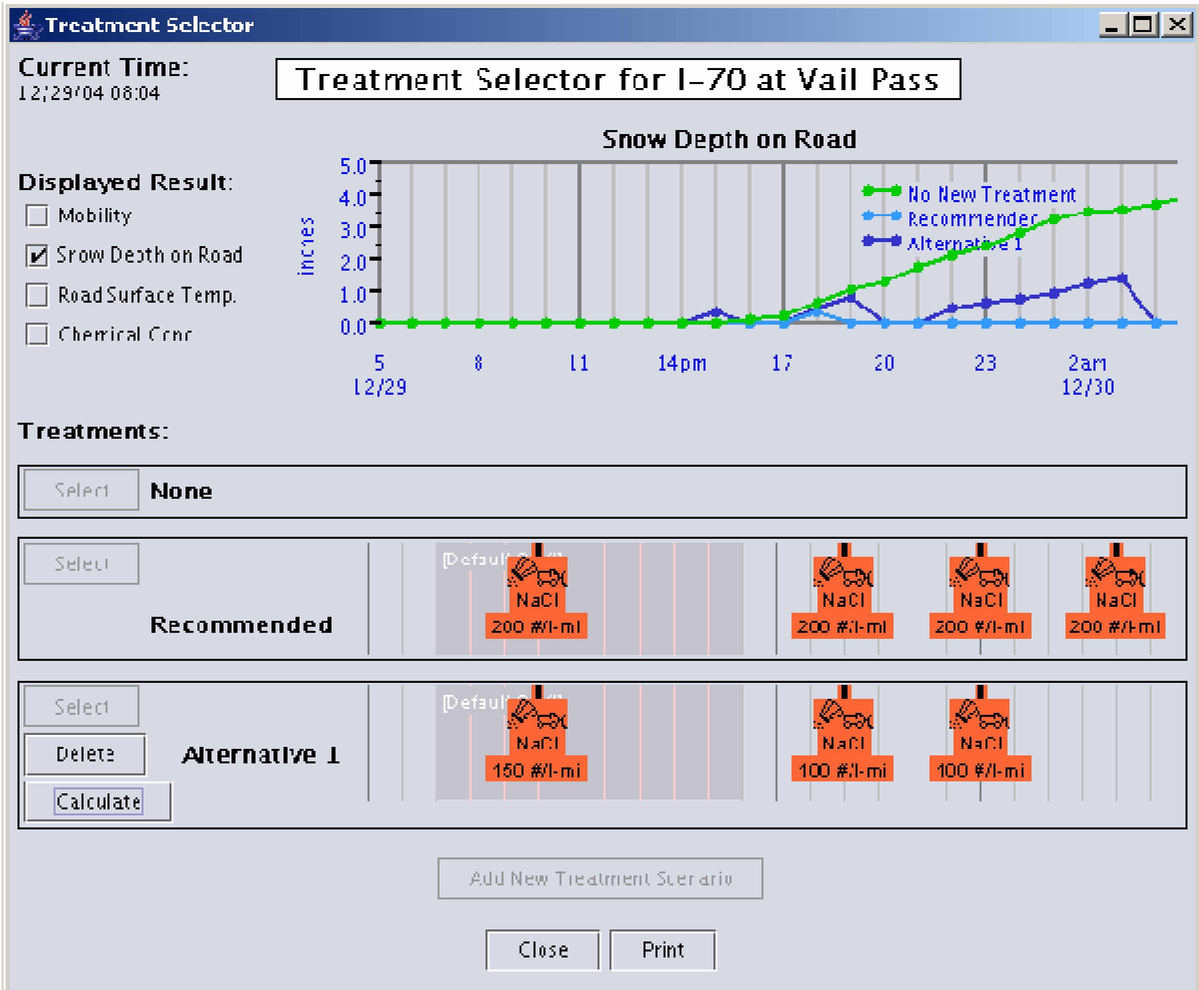

FIGURE 3 The MDSS "What-If" Scenario treatment selector. This what-if selector is provided with the MDSS prototype system. It provides a way for the operators to provide alternative treatment strategies including using different chemicals, application rates, and times. The result is provided as a time series (*top*) that shows the consequences of deviating from the recommended parameters. This capability can be used to work around scheduling conflicts or to test and see if changing the application strategy would still produce acceptable mobility on roads.

The MDSS prototype was demonstrated and evaluated over three winter seasons in Iowa and Colorado (*4*). While there are still scientific challenges to be overcome in both weather forecasting and understanding the complexities of winter road conditions, the MDSS project has been quite successful in bringing the winter maintenance and weather communities closer together and to help seed the weather service industry with new advancements.

FOCUS ON DEPLOYMENT

The FHWA has invested several years in funding and guiding the development of the MDSS prototype. However, the success of the program was not accomplished in a vacuum. A stakeholder group gathered at least annually during the multi-year requirements gathering and system development process. This group was used as a sounding board at each step and played a significant role in the GUI design and the selection of the type of forecast elements that were to be available to the end users. This stakeholder process also provided buy-in and involvement from the private sector. The ultimate deployment of MDSS will depend on the private sector recognizing that there is a market for these capabilities and that integrating (some or all) modules into their product lines is worth their investment.

By the end of 2005, FHWA had sponsored seven MDSS stakeholder meetings with interest and attendance continuing to climb with each. Figure 4 shows that from 2000 through 2005, 37 U.S. states (73%) participated in one or more MDSS stakeholder meetings. Oregon is shaded in brown because they have shown an interest in MDSS technologies but could not attend the meetings.

The MDSS deployment strategy, however, goes beyond just annual meetings. FHWA has a multi-faceted program to educate and promote deployment of MDSS technologies. The following sections highlight these strategies.

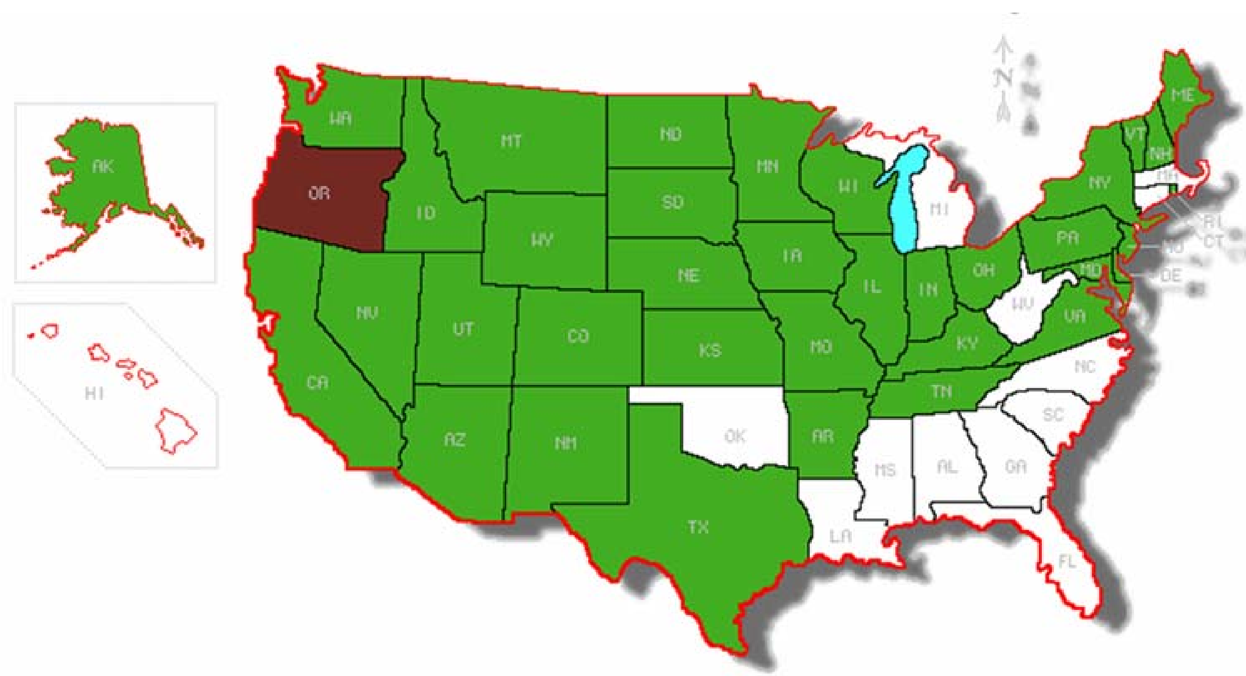

FIGURE 4 Thirty-seven states participated in at least one MDSS activity during the system development years of 2000–2005.

Technology Transfer

FHWA has established a multitiered technology transfer program for the deployment of MDSS technologies. Technical guidance is geared towards the two key stakeholder groups of state DOTs and private-sector weather service providers. For the state DOTs, the focus is on procurement of MDSS, and for the weather service providers, the focus is on technical implementation of the software. All MDSS prototype software has been made available at no cost. This includes all of the source code for the treatment algorithms, the numerical weather models and the Java-based GUI. The RWFS data fusion module is licensed to the National Center for Atmospheric Research (NCAR). However, they are making the object code available for free use for a year to allow interested parties to test and evaluate the entire package. Registration to receive the latest MDSS prototype software can be obtained at www.rap.ucar.edu/projects/rdwx_mdss/release3/.

During the summer of 2004, FHWA sponsored a full-day technology transfer workshop that allowed all interested parties to obtain copies of the latest software. Engineers and scientists that developed the system gave seminars and were available to answer questions. FHWA also funded NCAR to provide telephone support to any party that had procurement, installation, or operating questions about the MDSS prototype software.

Outreach and Education

Staff from FHWA's Road Weather Management program and scientists from NCAR have provided dozens of presentations and published numerous papers and articles on the development, evaluation and deployment of MDSS technologies. Some of the more well known organizations where MDSS presentations have been made include

- Transportation Research Board,
- American Meteorological Society,
- Intelligent Transportation Society of America,
- ITE,
- Standing International Road Weather Commission,
- World Road Association,
- American Public Works Association, and
- Canadian Meteorological and Oceanographic Society.

During the spring of 2004, FHWA co-sponsored the filming of a 30-min television program with The Weather Channel. The segment, called *Road Risk*, visually depicted the dangers of driving in wet, snowy, and icy conditions. DVDs of the program can be obtained from the FHWA Road Weather Management website at www.fhwa.dot.gov/weather/.

NCAR continues to maintain a website which serves as the main repository for MDSS prototype presentations and documentation. The site contains technical descriptions of the software, summaries from the stakeholder meetings, and tutorials on how to use the MDSS prototype GUI. The address for this site is www.rap.ucar.edu/projects/rdwx_mdss/.

Finally, FHWA has created a one-page flyer that provides background information, shows highlights of the MDSS prototype GUI and provides a list of potential benefits of using

MDSS technologies. The MDSS flyer can be downloaded from the FHWA Road Weather Management website.

Supporting Documentation

Several state DOTs have already begun to include requirements for MDSS functionality into their weather support contracts. To assist states in understanding what new technologies may be on the horizon and to help them understand how to incorporate the requirements for new technologies into their request for proposals (RFPs), FHWA's Road Weather Management program can provide technical assistance. NCAR has also created a document that provides a template for creating a MDSS-centric RFP. This document is available from www.rap.ucar.edu/projects/rdwx_mdss/documents/MDSS_Procurement_Template27Nov04.pdf.

In an effort to capture the state-of-the-art in weather forecasting and future trends, NCAR has also created the document "Road Weather Forecasting and Observations: Assessment of Current Capabilities and Future Trends." This document is available from www.rap.ucar.edu/projects/rdwx_mdss/documents/Weather_Observation_Prediction_Capability_Assessment_10Dec04.pdf.

DEPLOYMENT EXAMPLE: THE SOUTH DAKOTA POOLED FUND PROJECT

It took only until 2002 for several states to realize that technologies such as the MDSS may be a good investment. As the expectations for road mobility continued to rise by the traveling public and commercial carriers, state DOTs continued to be constrained by both funding and staffing. A core group of five states pooled funds to begin development of an operational MDSS.

The pioneering group of states in the pooled-fund (PF) effort included South Dakota (as the lead state), Indiana, Iowa, Minnesota, and North Dakota. During 2005, three additional states—Colorado, Kansas, and Wyoming—joined the pool. The states along with their contractor, Meridian Environmental Technology, had as their goal to build and evaluate an operational and sustainable MDSS to improve the ability to forecast road conditions in response to changing weather and applied maintenance treatments.

The essential elements of the PF MDSS include (*5*)

- Reporting actual road surface conditions,
- Reporting actual maintenance treatments,
- Assessing past and present weather conditions,
- Assessing the present state of the roadway,
- Predicting storm-event weather,
- Recognizing resource constraints,
- Identifying feasible maintenance treatments,
- Predicting road surface behavior, and
- Communicating recommendations to supervisors and workers.

To realize these essential elements, the PF team not only had to build upon the foundational work completed in the FHWA MDSS prototype, but expands upon it by adding new innovations. This included equipping snowplows with Global Positioning Satellite (GPS) automated vehicle location (AVL) devices that are capable of reporting weather conditions and equipment status (e.g., plow blade position). The goal was to be able to obtain in near real-time the location of each truck, the plow blade position, the chemical application rate, and the types of materials used. There were also other challenges such as communicating the state of the road surface (e.g., snow depth) into an automated system.

Like the FHWA MDSS prototype, the PF MDSS used a series of weather models and a pavement model that provided forecast guidance on elements such as pavement temperature, pavement chemical concentration, pavement moisture types and depths. However, unlike the FHWA MDSS prototype, the PF MDSS predicts road conditions and recommends maintenance treatments on the basis of physical modeling, rather than rules of practice. The PF MDSS added radar data, near term (tactical, under 6 h) forecast support, and the provision for meteorologist intervention in the weather forecast process. Also different in the PF MDSS is the capability for the operator to select either an optimal treatment recommendation (e.g., safety first, cost considerations second), or a standard treatment based solely on local maintenance practices. Finally, similar to the prototype, the PF MDSS has a “what-if” capability to allow the user to try any number of alternative maintenance actions and see the resulting forecast effects on the road surface (*6*).

Figure 5 shows an example of the PF MDSS main display with radar data overlaid on a highway map. The different colors represent precipitation phase (liquid, freezing, and frozen). The box in the center of the screen shows an observation from a snowplow with GPS–AVL equipment reporting location, weather and road conditions.

Figure 6 provides an example of the PF MDSS forecast and treatment recommendation screen. Through the use of graphical visualization, the series of tables shows probabilities of precipitation, snow accumulations, precipitation types, forecast road conditions, treatment recommendations, and forecast road temperatures.

NEXT STEPS FOR MDSS

The FHWA MDSS prototype continued its limited deployment in Colorado during the winter of 2005–2006 where there is continued evaluation of how the system operates in complex terrain. This was sponsored by the E-470 Public Highway Authority and the City and County of Denver, Colorado. The PF MDSS was also undergoing field trials during the winter of 2005–2006 in the eight PF states. Once an evaluation is completed, full deployment is expected in 2006 and 2007.

During the 2005–2006 and 2006–2007 winter seasons, the participants in the PF MDSS project plan to expand field trials to include more locations in the eight participating states and more extensive use of vehicles equipped with on-board instrumentation and AVL. The project will include validation of forecasts of weather, road conditions, and treatment effectiveness, as well as refinement of physical models and software. Finally, the project will address issues relating to statewide deployment, including operational environments, business models, and linkages to other state information systems. The ultimate goal of the project is to provide a sustainable, fully functional, and easily scalable MDSS to support the needs of transportation agencies.

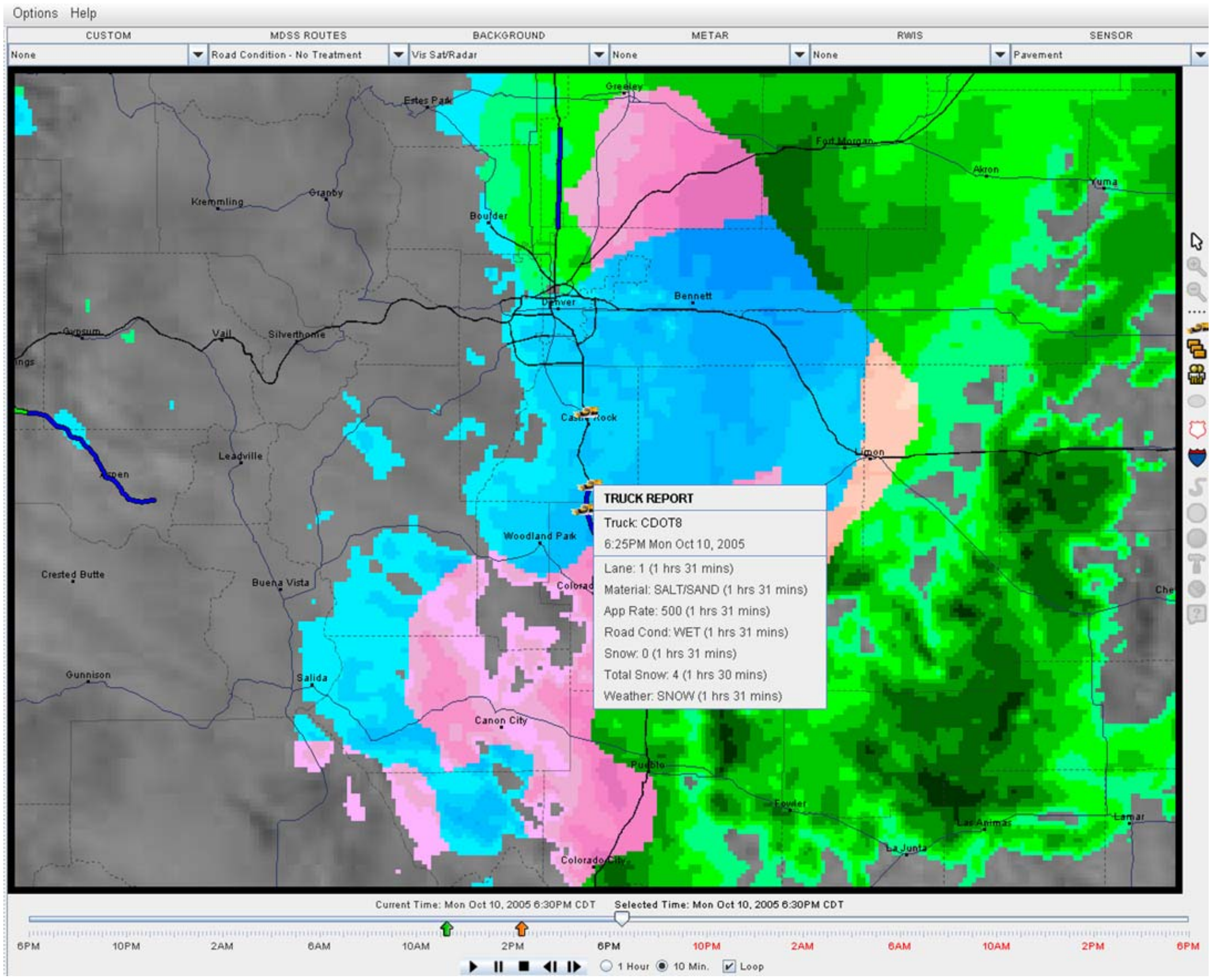

FIGURE 5 The PF MDSS main display. The PF version of the MDSS GUI not only provides high-resolution backgrounds and observations but also provides data from mobile observations and color-coded weather radar.

FHWA will continue to actively promote the deployment of MDSS throughout 2006 and beyond, including further efforts pertaining to all the technology transfer items described above, as well as possible field evaluations. In addition, FHWA is planning on sponsoring a MDSS stakeholder meeting in late summer–early fall 2006. Updates on both programs as well as new deployment initiatives will be discussed. It’s clear that deployment of such a complex system takes time. State DOTs must be confident that the services provided by the private-sector work as they should and reap benefits. Private-sector providers must have the technical wherewithal to provide the services, and know that their investments will be profitable. While there is every reason to think that both sets of needs can be met, it will still take time to get there.

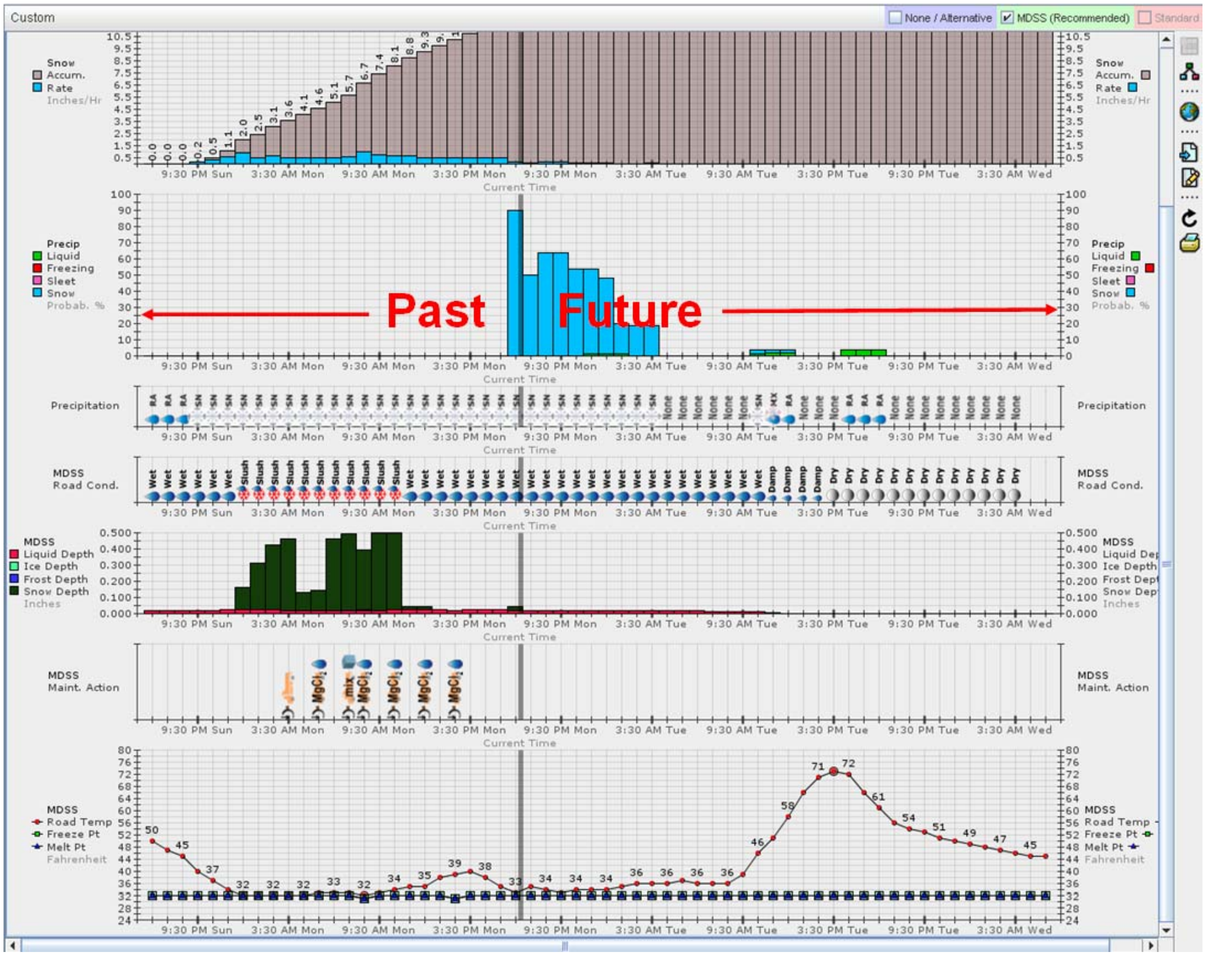

FIGURE 6 The PF MDSS forecast treatment recommendation screen. Like the prototype MDSS display, the PF version provides advanced visualization graphics on precipitation type and accumulation, road temperature forecasts, and treatment recommendations specifically tailored for winter maintenance personnel.

CONCLUSION

In an effort to create a link between the winter road maintenance and meteorological communities, the FHWA has directed and funded a multifaceted campaign to both develop a MDSS and to provide technology transfer support and outreach so that the greater community understands and embraces these technologies. The FHWA will be able to claim success in this endeavor if state DOT agencies create a market for these advanced technologies and the private sector moves to integrate these capabilities into their product lines.

A significant step has already been taken by a group of eight state DOTs as they have pooled their resources to develop a customized MDSS for their agencies. FHWA continues to provide technology transfer support and educational outreach activities to assist all parties in understanding and nurturing this concept into reality. The benefits to everyone in the success of this project are safer roads, more efficient use of resources, and more targeted (reduced) use of chemicals.

REFERENCES

1. Pisano, P. A., A. D. Stern, and W. P. Mahoney. The U.S. Federal Highway Administration Winter Road Maintenance Decision Support System (MDSS) Project: Overview and Results. Presented at 21st International Conference on Interactive Information Processing Systems, American Meteorological Society, San Diego, Calif., 2005.
2. Mahoney, W. P., B. Bernstein, J. Wolff, S. Linden, W. Myers, R. Hallowell, J. Cowie, A. Stern, G. Koenig, G. Phetteplace, P. Schultz, P. Pisano, and D. Burkheimer. FHWA's Maintenance Decision Support System Project: Results and Recommendations, *Transportation Research Record: Journal of the Transportation Research Board, No. 1911*, Transportation Research Board of the National Academies, Washington, D.C., 2005, pp. 133–142.
3. Mahoney, W. P., and W. Myers. Predicting Weather and Road Conditions: Integrated Decision Support Tool for Winter Maintenance Operations. *Transportation Research Record*: *Journal of the Transportation Research Board, No. 1824*, Transportation Research Board of the National Academies, Washington, D.C., 2003, pp. 98–105.
4. *The Maintenance Decision Support System (MDSS) Project Technical Performance Assessment Report, Colorado Field Demonstration Winter 2004-2005*, Version 1.0, National Center for Atmospheric Research, Boulder, Colo., September 2005.
5. Huft, D. L. *Maintenance Decision Support System Pooled Fund Study TPF-5(054)*. Presented at MDSS Stakeholder Meeting, October 20, 2005, Boulder, Colo., www.rap.ucar.edu/projects/rdwx_mdss/plans_reviews/Sess3-MDSS_for_Stakeholders_Huft2_talk3.pps
6. Mewes, J., R. Hart, L. Osborne, and B. Podoll. The Pooled Fund Study Maintenance Decision Support System: A Functional Overview. Presented at 21st International Conference on Interactive Information Processing Systems, American Meteorological Society, San Diego, Calif., 2005.

PART 4: WINTER MAINTENANCE

Winter Performance Measures in Alberta, Canada

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Performance measurement is a vital component of asset management, which is used in planning and programming to identify assets that are under or over performing and to assess overall performance. As part of the move to asset management, Alberta Infrastructure and Transportation has implemented performance-based planning and monitoring of the provincial highway network. Furthermore, since Alberta is a winter province, a clear suite of performance measurement tools is required for snow and ice control. Traditionally agencies have measured inputs or outputs, but none of the existing measures address effectiveness. Standards are in place for times to correct pavement to a certain condition after a storm ends, yet monitoring of these standards is not done consistently across the province or summarized for others to see. This paper presents the results of a project to develop winter performance measures that are outcome based for a large rural highway network.

This paper includes results of an extensive pilot project which was carried out in the winter of 2004–2005 on approximately 300 km of Highway 2 from Calgary to Edmonton. The pilot project evaluated the use of several factors for performance measure development. These measures included the good, fair, and poor ratings provided by maintenance contractors and reported for public use through the provincial motor association, collision and run-off-the-road incidents, and vehicle speed and volume distributions during storm events. Categorization of storm events was a further subject of study. The paper concludes with recommendations for further work for the winter of 2005–2006.

INTRODUCTION AND BACKGROUND

As part of a governmentwide infrastructure management initiative, Alberta Infrastructure and Transportation has implemented performance-based planning and monitoring of the provincial highway network. Three performance measure categories, based upon technical measurements, have been adopted which characterize condition, functional adequacy and utilization, and these categories are used across government for capital planning purposes (*1*). However, no clear suite of outcome-based performance measures has been developed for snow and ice control. This report will summarize work done by the University of Calgary in the summer of 2004 (*2*), and the results of a pilot project done during the 2004–2005 winter in an attempt to implement outcome-based winter performance measures. The University of Calgary work was also reported in a paper presented at the 85th Annual Meeting of the Transportation Research Board in Washington, D.C., in January 2006 (*3*).

Performance measures are used by agencies to

- Define policy objectives at an early stage of policy or system planning;
- Provide the basis for annual performance reporting on system condition and performance as part of communication;
- Screen projects or set priorities; and
- Allocate resources (*4*).

Performance measures should be defined in response to the goals and objectives, which are directly aligned with the broad goals and mission, of the agency. To be effective, performance measures should be based upon technically sound data, understandable to all levels of the agency, and reflect user or stakeholder groups.

Most agencies have historically measured outputs (that is, tonnes of materials placed or manpower costs) for snow and ice control performance measurement. However, effectiveness measures have become necessary due to an increased focus on customer needs.

One of the difficulties in snow and ice control is of course the weather and the huge impact storm intensity, duration, and geographic variability can have on measuring efficiency or effectiveness of maintenance activities. Weather variability complicates the business of assessing the relative efficiency of different road maintenance programs. Categorization of storm events therefore becomes important. For this study, the performance measures considered can be grouped into four categories: safety, mobility and reliability, level of service (LOS), and customer satisfaction.

SURVEY OF OTHER JURISDICTIONS

A global review of what other jurisdictions are doing for snow and ice control measures is contained in the University of Calgary report (*2*). The measures found relate to direct costs and benefits, rate of compliance with defined LOSs, actual versus predicted expenditures, safety, time to clear snow after the end of a storm, friction values, tons of salt placed and customer satisfaction ratings.

THE ORIGINAL UNIVERSITY OF CALGARY STUDY

The objectives of the original study (*2*) were

- "…to develop meaningful, pragmatic performance measures for department maintenance operations during and after winter snow and ice occurrences";
- "The performance measures developed must be practical, repeatable, and understandable and must reflect the input of user or stakeholder groups"; and
- "Data collection aspects must be a strong consideration."

The study involved a workshop with internal department experts on maintenance and winter operations and an external workshop with the Royal Canadian Mounted Police, the Alberta Motor Association, the Alberta Motor Transport Carriers Association, the Student Transport Association of Alberta, the associations representing the local rural and urban counties and two maintenance contractors. A representative was also present from the federal department responsible for weather forecasting.

Tentative measures that came out of the workshops and original study revolved around

- Customer satisfaction surveys: A provincial survey was anticipated to gauge public reaction to the effectiveness of provincial winter maintenance operations.
- Safety: Collision rates, tow truck calls, and run-off-the-road incidents.
- Mobility and reliability:
  - Percent of time that the mean speed was maintained during storm event differentiated by storm category.
  - Percent of time that the volume was maintained during storm event differentiated by storm category.
  - Time to recover to mean speed and volume after the end of storm differentiated by storm category.
- LOS:
  - Percent of time that the road is in good–fair–poor driving condition (as defined by road reports) during storm events differentiated by storm category.
  - Time to recover skid resistance to acceptable values.

These concepts are discussed briefly below.

Customer Satisfaction Surveys

The development of an outcome-based performance measure relative to customer satisfaction indeed has merit, as who can better assess the adequacy of road conditions than the road users themselves. However, carrying out such an initiative must be done very carefully and judiciously by survey experts. Some of the issues that would need to be addressed include, but are not limited to

- Would the surveys be widespread or would they deal with specific focus groups only, or both?
- Would the surveys be conducted for the entire winter in general terms, or for specific storms in specific locations only, or for both?
- How would consistency be obtained in the survey results, i.e., would results vary by geographic region or would good-fair-poor have adequate descriptions?
- How much would such an initiative cost?
- How would the results be used?

Because of these issues, it was decided that the customer survey portion of the project would be delayed until after the pilot project was completed. It was also decided that, if this initiative were re-enacted in the future, the first activity that would be undertaken would be an extensive survey of what other jurisdictions were doing for winter performance and also for other highway service areas.

Safety

The use of safety incidents of one type or another to define differences between weather-related and non-weather-related events also appears to be attractive. The varying levels of maintenance could then hopefully be reflected by the differences in recorded incidents.

Mobility and Reliability

These measures would reflect a highway's ability to maintain operations at near normal levels and to return to those levels as quickly as possible.

Level of Service

These measures reflect the winter driving condition service levels experienced by the road user on a continual basis using a good–fair–poor rating system.

Another measure that is to be considered is the use of skid resistance measurements to determine LOS. The objective of using skid resistance ratings is to objectively quantify the boundaries for good–fair–poor ratings and to determine the length of time it would take to recover those ratings to acceptable values. While equipment does exist to measure the skid resistance of a segment of road, the challenge would be to come up with ratings on a continual basis and to come up with the rating boundaries. Data issues with skid resistance ratings are

- Cost,
- Frequency of data collection,
- Benchmarks,
- Liability implications, and
- Maintenance contract implications.

Because of the complexity of these challenges, it was decided to not pursue this measure during the pilot project.

Weather Events

All of the measures studied to date will, of course, depend on the severity of the winter or the number of storm events that occur. It will be necessary when developing an outcome-based measure to basically have some indicator that can be used to compensate for these varying degrees of weather/winter if one is to get a measure of maintenance effectiveness. An agency can control the level of maintenance that they perform, but they cannot control weather.

Severe Weather Events

Mobility and reliability measures which involve speed reductions will be impacted by severe weather events. The level of maintenance performed during these severe events will be difficult to measure and thus need to be handled separately. This then requires a definition of a severe event. As a starting point for this project the definition used was "An event will be considered a 'severe event' if: a) the total snow during the event is greater than 8 cm, **or** visibility is less than one km and the mean speed is less than the ‘normal’ lower limit, **or** freezing rain is occurring and the mean speed is less than the ‘normal’ lower limit.” This allowed analysis as described in the Pilot Project section below.

THE PILOT PROJECT

It was felt that before any detailed performance measures should be proposed, several possibilities would have to be assessed on a pilot project basis. The highway selected for the trial was the QE II (Highway 2 between Calgary and Edmonton). The trial would be done over the winter of 2004–2005. The purpose of the trial was to determine what performance measures appeared reasonable.

This section of highway contains two weigh-in-motion sites from which traffic volumes, vehicle classification and vehicle speeds can be determined on a continual basis. As well there are Environment Canada weather stations in close proximity to the weigh-in-motion sites.

Safety

For the safety component of the project, three areas were investigated. Collision data was obtained from the department traffic safety division and collision rates were calculated for periods when snow was falling and for those periods when no snow was falling. As well, the department partnered with the provincial motor association (AMA) and had that association collect data on the number of tow truck calls that occurred along this highway also during snow and non-snow times. Lastly the department partnered with the maintenance contractor for this section of highway and had them record run-off-the-road incidents by checking evidence of this from vehicles either in the ditch or having left evidence of having been in the ditch. The results of the safety analysis are contained in Table 1.

Issues with the incident data are

- Time consuming and expensive to collect (tow truck calls and run-off-the-road);
- Small sample sizes for some months (all three areas);
- Time lag for use of data would be large because of the processing times involved (collision rates);
- Accuracy and currency of the data (location, interpretation of forms used) (tow truck calls and run-off-the-road);
- Collision incidents are impacted by many other factors (collision rates); and
- Difficult to come up with benchmarks of what is acceptable (all three areas).

It was therefore concluded that the safety–incident data would not be pursued as a winter performance measure.

TABLE 1 Safety Incident Results, Trail Project, QE II, Edmonton to Ponoka

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total
Off Road								
Snow	—	—	Partial	112	23	50	0	185
No Snow	—	—	Partial	19	7	0	0	26
Rate/Snow Day	—	—	Partial	10.18	4.60	4.55	0	6.61
Rate/Non-Snow Day	—	—	Partial	0.95	0.30	0.00	0	0.34
Tow Truck Call								
Snow	—	—	49	51	20	18	0	89
No Snow	—	—	3	24	2	0	0	26
Rate/Snow Day	—	—	3.77	3.77	4.00	1.64	0	2.17
Rate/Non-Snow Day	—	—	0.17	0.17	0.09	0.00	0	0.27
Collisions								
Snow	—	1	15	—	—	—	—	16
No Snow	—	22	10	—	—	—	—	32
Rate/Snow Day	—	0.50	1.15	—	—	—	—	1.07
Rate/Non-Snow Day	—	0.79	0.56	—	—	—	—	0.70
# of Snow Days	0	2	13	11	5	11	1	43
# of Non-Snow Day	16	28	18	20	23	20	14	137

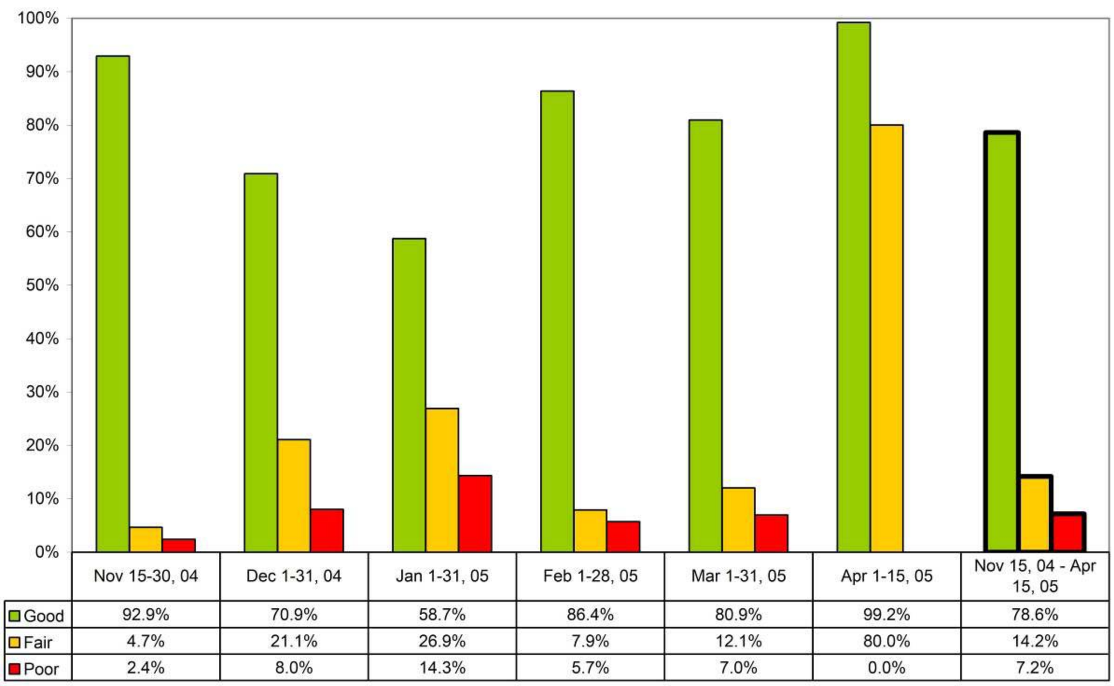


FIGURE 1 Good–fair–poor rating by month and total for 2004–2005 winter, Trail Project, QE II, Edmonton to Calgary.

Good-Fair-Poor AMA Ratings

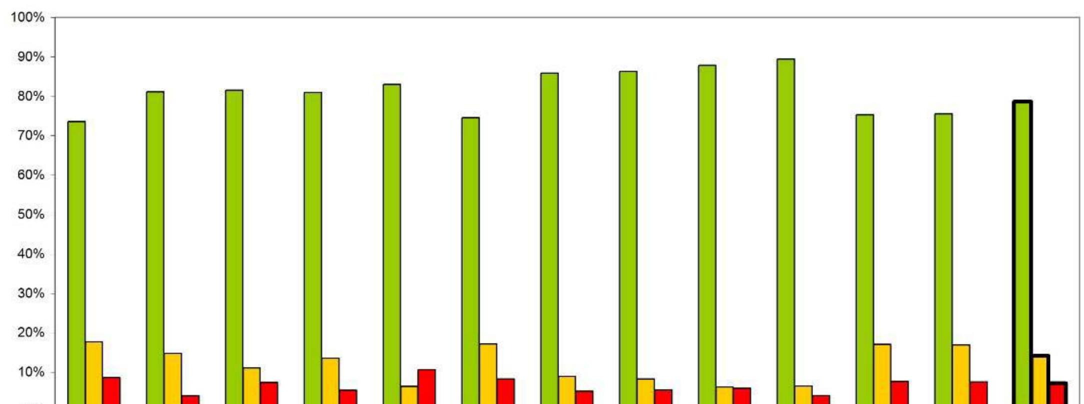
Good–fair–poor ratings for winter driving conditions along the entire Highway 2 between Calgary and Edmonton for the 2004–2005 winters were captured electronically on a continual time basis. This information was then analyzed and percentages of good–fair—poor were calculated for each month and the total, weighted by length. The results are shown in Figure 1. Figure 2 shows the results by segment of highway for the entire winter.

Issues with the good–fair–poor data are

- The subjective ratings may not have been applied consistently.
- The data may not all be current (ratings are normally done once a day or more often if conditions change, however, the "more often" is not always done consistently).
- Segment lengths may not always be homogeneous. In some cases they may be too long and may not adequately indicate condition over that complete length.
- These ratings are done for two-digit highways and not for the three-digit "secondary" highways.
- Levels of good–fair–poor will vary by severity of winter, thus stressing the need for some adjustment based on a severity index.
- No benchmarking information is available.

Mobility and Reliability

The mobility and reliability factors assessed involved traffic volumes and vehicle speeds as determined at a weigh-in-motion site. The site selected was a site near the Edmonton end of the project and close to the weather station at the Edmonton International Airport (hereinafter



	Calgary - S. of Bowend	S. of Bowden - Innisfail	Innisfail - Penhold	Penhold - Hwy 11A	Hwy 11A - Blackfalds	Blackfalds - Morningside	Morningside - Ponoka	Ponoka - Hobbema	Hobbema - Wetaskiwin	Wetaskiwin - Millet	Millet - Leduc	Leduc - Edmonton	Overall
% Good	73.6%	81.1%	81.6%	81.0%	83.0%	74.6%	85.9%	86.3%	87.9%	89.4%	75.3%	75.6%	78.6%
% Fair	17.8%	14.8%	11.1%	13.6%	6.4%	17.1%	8.9%	8.3%	6.2%	6.5%	17.1%	16.9%	14.2%
% Poor	8.7%	4.1%	7.4%	5.5%	10.6%	8.3%	5.2%	5.5%	5.9%	4.1%	7.6%	7.5%	7.2%

FIGURE 2 Good–fair–poor rating by highway segment for 2004–2005 winter, Trail Project, QE II, Edmonton to Calgary.

referred to as the Leduc site). Reductions below a pre-determined “normal” value were used to assess the impact of a weather event.

The analyzed data for the volume factor is shown in Figure 3. Figure 3 shows volume variations plotted against weather events (source: Environment Canada weather data) and the AMA good–fair–poor ratings. Issues with the volume data are

- Volume reductions often occur as a result of other events–factors.
- The data is only available at automated traffic recorder sites and weigh-in-motion sites.
- Volume reductions may just be a measure of the effectiveness of a communication strategy that encourages drivers to stay off the road in poor conditions and not of the road condition or maintenance activities themselves.

For these reasons, it was decided not to continue analysis of volume as a measure.

The analysis data for speeds is presented in Figure 4 which shows an apparent relationship between speed reduction and weather events. To follow-up on this factor, mean speeds were calculated for snow times and non-snow times for the month of January and for the entire winter at the site in question. The mean speeds were also calculated excluding times that were defined as severe events (see description in the section on the original University of Calgary study above). The resultant mean speeds were then calculated as percentage of normal, which was defined as mean speed minus one standard deviation. The percentage of time at which speeds were less than normal was also calculated. Results are shown in Table 2.

Table 2 indicates that during the month of January 2005 the mean speed during snow events was 91.1% of the mean speed during nonsnow events (excluding severe events that were not snow related, e.g., visibility). For the entire winter the corresponding number is 94.7%. The percentage of the total time during the month of January when the speed was less than normal was 11.8, whereas for the entire winter it was 4.0. The percentage of the time when the speed was less than normal during January and which could not be explained by a severe event was 54.5, whereas for the entire winter the corresponding percentage was 41.5.

TABLE 2 Vehicular Speed and Weather Events, Trail Project, QE II, Leduc Site

		January	**October 15–April 15**
Mean speed (kph)	Snow	103.7	110.7
	Snow excluding SE	107.1	112.0
	Non-snow	113.8	117.0
	Non-snow excluding SE	114.3	117.1
% of normal speed	Snow	91.1%	94.7%
	Snow excluding SE	93.7%	95.6%
% of time < normal		11.8%	4.0%
% of time < normal (excluding SE)		45.5%	41.5%

SE = severe event

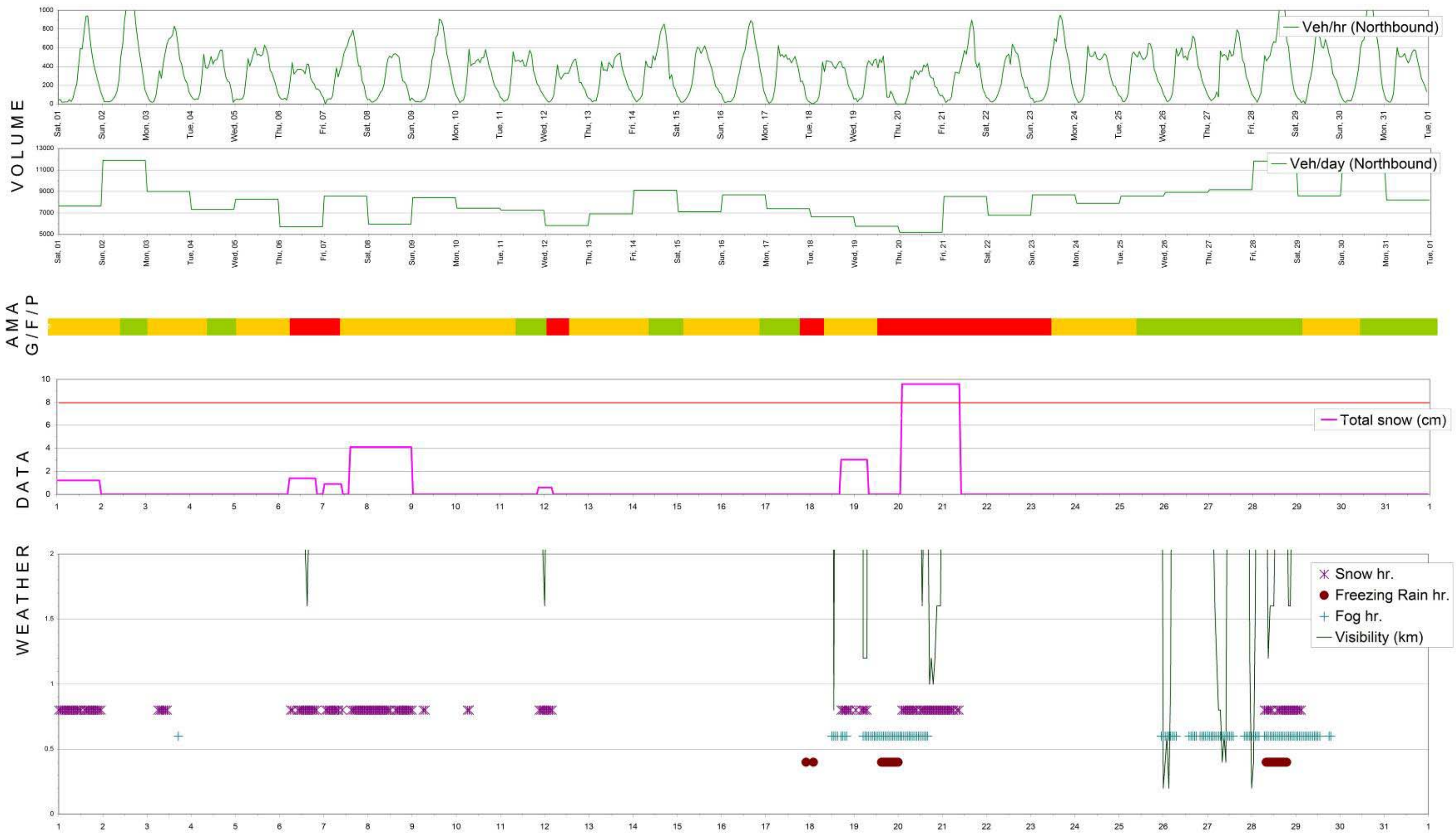


FIGURE 3 Traffic volume and weather event data, Trial Project, QE II, Leduc site.

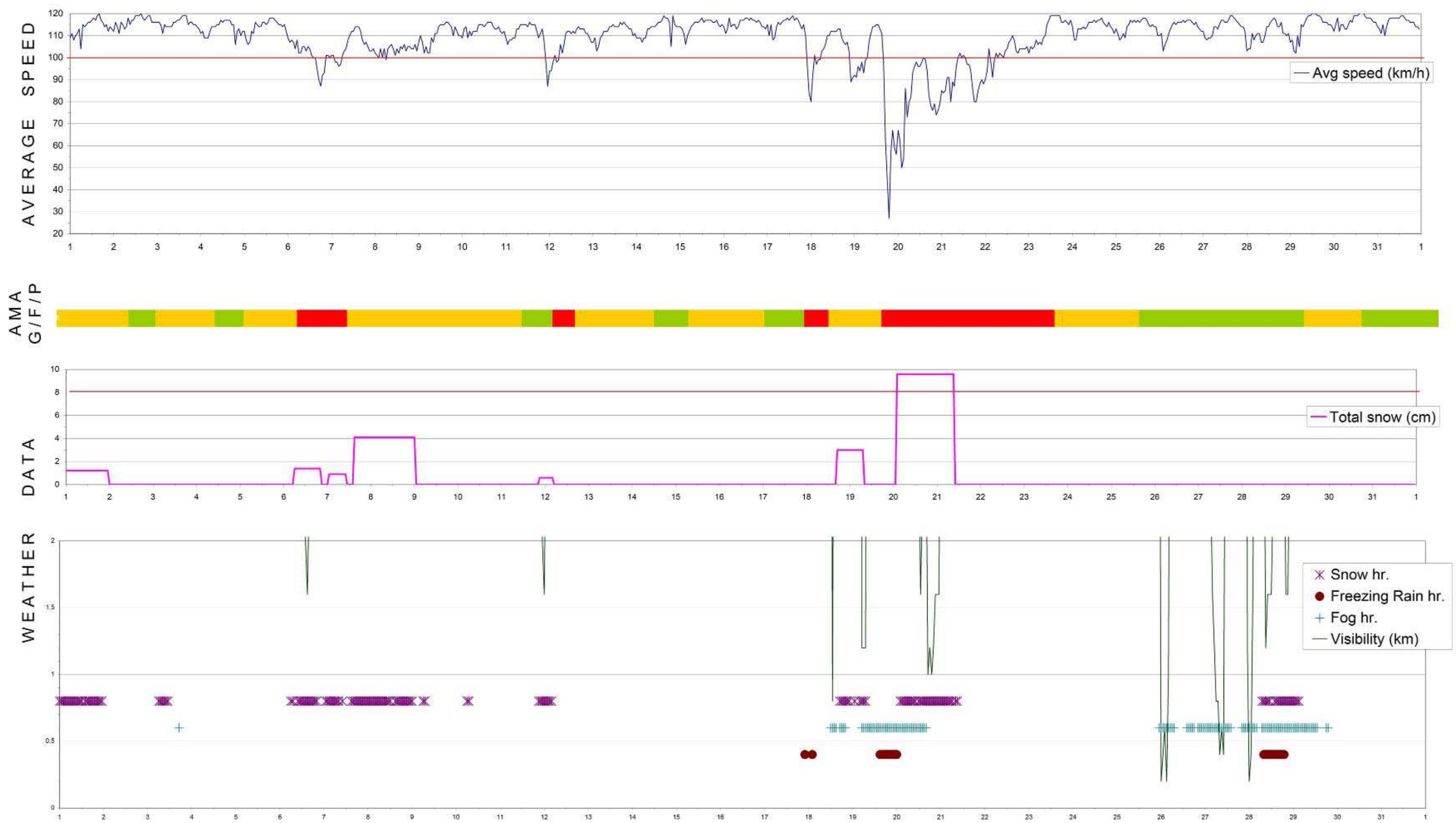


FIGURE 4 Average speed and weather event data, Trial Project, QE II, Leduc site.

Issues with the speed data are

- The data are only available at weigh-in-motion sites (presently only six in the province).
- Speed reductions may occur as a result of other events–/factors.
- The definition of extreme events requires verification.
- The definition of normal speeds requires verification.

Recovery Time

This factor has not yet been thoroughly analyzed pending verification of the definitions of normal speed and severe event. The department maintenance specifications (*5*) are contained in Table 3 and state the "maximum time to good winter driving conditions." The speed data may in future be used as an alternate way to measure that time. Once extreme events and normal speeds are verified recovery times can be calculated and analyzed and the merits of adopting such a measure can be assessed.

CONCLUSIONS AND NEXT STEPS

The study done to date indicates that the areas that show the most promise for the development of outcome based winter performance measures are two in number: the areas dealing with good–fair–poor condition ratings and speed reductions. The measures need to be tied to either the severity of the winter or the number of storm occurrences of varying severity during the winter.

TABLE 3 Winter Level of Service (Rural Highways)

Class of Highway	Traffic Volume (AADT)	Maximum Reaction Time* (hours)	Maximum Time to Good Winter Driving Condition** (hours)	Typical Reaction Time (hours)
A	> 15,000	2	6	1
B	7,000–15,000	4	6	1
C	5,000–7,000	4	8	2
D	2,000–5,000	4	8	2
E	1,000–2,000	6	12	3
F	500–1,000	8	12	3
G	100–500	12	18	4
H	<100	16	24	5

*Maximum time allowable for equipment to have commenced work from the time of a 3 cm accumulation. This value represents the maximum time that will be required to respond after an average winter storm. Normally, equipment will begin work during most storm events and as a result most roads are cleared faster than the maximum time indicated.

**Good winter driving conditions exist when snow and ice have been removed from the driving lanes and excessive loose snow has been removed from the shoulders and centerline of highway. Short sections of ice and packed snow are acceptable and can be expected within the driving lanes between the wheel paths, as well as on centerline.

Wording of the performance measures for the speed reduction area still needs to be finalized, but may centre around percentage of normal speed achieved during storm events and percentage of time speeds are less than normal (including or excluding severe events). A measure should likely also be developed around recovery times.

Further work required includes

- Verification of definitions for normal speed and severe event;
- Multi-year analysis to establish benchmarks and targets;
- Refine wording and reporting requirements; and
- Additional work on surveys and skid resistance.

REFERENCES

1. Cowe Falls, L., and R. Jurgens. Four Rs of Performance Measurement: The Alberta Case Study, Presented at the 82nd Annual Meeting of the Transportation Research Board, Washington, D.C., 2003.
2. Cowe Falls, L. Performance Measures for Snow and Ice Occurrences, Alberta Infrastructure and Transportation, Winter 2004–2005.
3. Cowe Falls, L., R. Jurgens, and J. Chan. Performance Measures for Snow and Ice Control in the Province of Alberta. Presented at the 85th Annual Meeting of the Transportation Research Board, Washington, Washington, D.C., 2006.
4. Pickerell, S., and L. Neumann. Use of Performance Measures in Transportation Decision-Making. TRB Conference on Performance Indicators, 2001.
5. Alberta Infrastructure and Transportation. *Highway Maintenance Guidelines and Level of Service Manual*, June 14, 2000.

PART 4: WINTER MAINTENANCE

Ohio Department of Transportation Road Grip Tester Project

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Ohio Department of Transportation

The Ohio Department of Transportation (ODOT) has initiated a process to create a system that detects, records, reports, and disseminates informational data regarding low grip areas on roadway surfaces. A Road Grip Tester (RGT) system measures road surface friction by utilizing an existing hydraulic system to deploy and retract a wheel that is located in the front of the drive axle underneath the vehicle or using a wheel mounted to a tow hitch at the rear of the vehicle. In normal, dry conditions a graphical display in the cab of the vehicle will show green lights (along with a corresponding numerical value). As the surface loses friction (e.g., wet or snowy conditions), more lights are displayed and the color changes from green to yellow; the numerical value changes decreases as well. As the road becomes snow covered, even more lights are displayed and the color changes to red. The numerical value decreases even further.

The intent of the system is to serve as an early alert and advance notification system for road conditions before, during, and after a winter event. The RGT provides the ability to detect deteriorated pavement surface conditions associated with winter weather that are otherwise not visibly evident. The system provides information allowing ODOT maintenance forces to detect the presence of black ice on pavement surfaces and prompt immediate treatment where needed. It also provides real-time information to detect the rapidly changing conditions associated with winter maintenance activities.

OVERVIEW

The Ohio Department of Transportation (ODOT) is evaluating a process to create a system that detects, records, reports, and disseminates informational data regarding low grip areas on roadway surfaces. Low grip readings are an indicator of low friction values of the given pavement surface. Based on low grip readings and associated data, advisories and alerts could be sent to various outlets (radio, television, cell phone, message signs, advisory radio, etc.) to relay the information to the motoring public regarding areas of slick pavement. Additionally, operational modes could be implemented by ODOT to treat the detected areas, or modify treatment types of areas based upon measured conditions.

The current Road Grip Tester (RGT) system measures road surface friction by utilizing an existing hydraulic system to deploy and retract an independent wheel of by using a wheel mounted to a tow hitch. Depending upon unit type, the wheel is located in the front of the drive axle underneath the vehicle or mounted to a tow hitch at the rear of the vehicle. In normal, dry conditions a graphical display in the cab of the vehicle will show green lights (along with a corresponding numerical value). As the surface loses friction (e.g., wet or snowy conditions), more lights are displayed and the color changes from green to yellow; the numerical value decreases as well. As the road becomes snow covered, even more lights are displayed and the color changes to red. In icy conditions, such as black ice, more lights and an even lower numerical value are displayed. Figure 1 and Figure 2 illustrate the typical unit configuration.

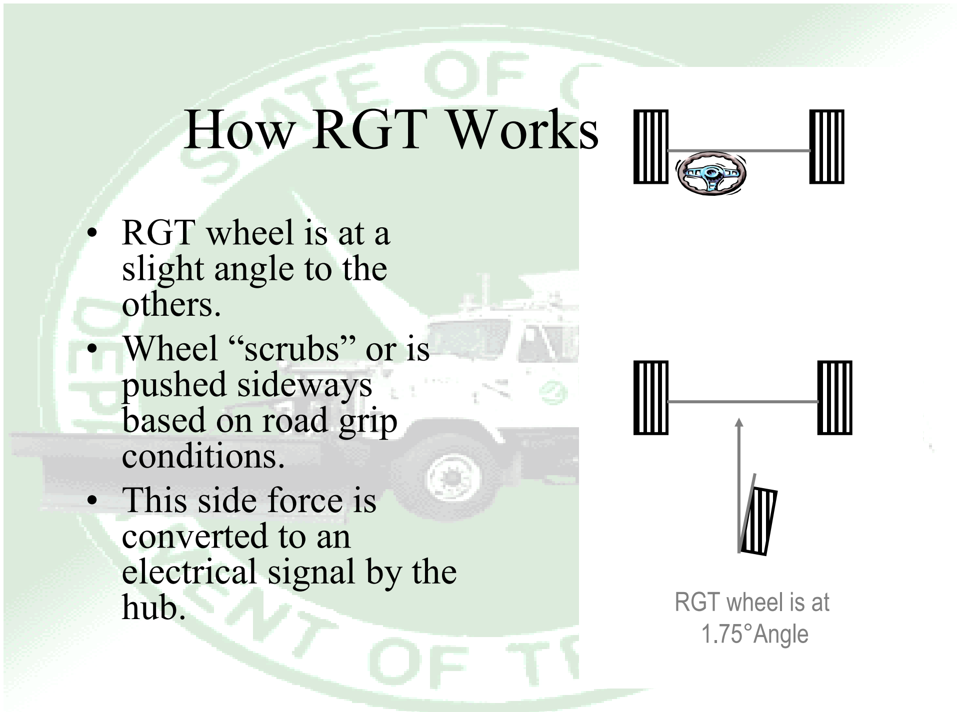

FIGURE 1 How the RGT works.

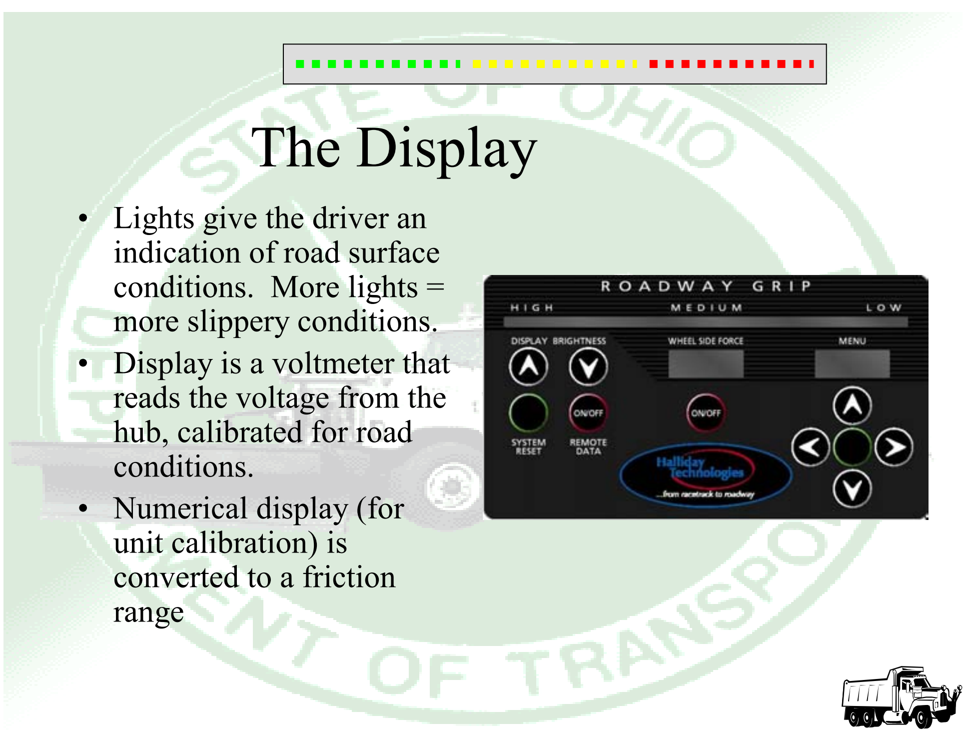

FIGURE 2 The display.

The intent of the RGT system is to serve as an early alert and advance notification system for road conditions before, during, and after a winter event. The RGT provides the ability to detect deteriorated pavement surface conditions associated with winter weather that are otherwise not visibly evident. The system provides information allowing ODOT maintenance forces to detect the presence of black ice on pavement surfaces and prompt immediate treatment where needed. It also provides real-time information to detect the rapidly changing conditions associated with winter maintenance activities. Data from the RGT can be used to validate the necessity of treatment types by verifying the presence or absence of black ice. Data may also be used to determine treatment effectiveness during a winter event. The RGT is intended to supplement other weather information tools currently available to ODOT (e.g., roadway weather information system, weather monitoring services, etc.), but not replace them.

Once icy or deteriorated conditions are detected, appropriate actions could potentially be employed. Actions such as informing the motoring public via various means (radio stations, television stations, cell phones, permanent changeable message signs, highway advisory radio systems), implementing operational modes to necessitate required treatment, and providing insight for treatment adjustment based upon varying conditions, could be selected for implementation.

BACKGROUND

ODOT's prototype RGT was designed and manufactured by Halliday Technologies, Inc., a local Columbus, Ohio, company that brought their grip measuring techniques over from the racing industry. Halliday Technologies has had many successful years testing side loading of a tire on vehicles in use. In 1995 Don Halliday patented a device which measures grip on all four corners of a vehicle. The device has been used successfully in Indycar, Championship Auto Racing Teams, and National Association of Stock Car Auto Racing. The Halliday design has been adopted by a major tire company for tire development. It creates very little mechanical friction in the load measurement direction and thus has very good electro-mechanical side force resolution with very low drag. No water is needed, no breaking required, and data is available continuously at any speed. The device provides a continuous fingerprint of the friction between tire and track surface (*1*).

Through meetings with ODOT and Halliday Technologies, Inc., the design for the winter maintenance, truck mounted version of the friction sensor was created. The RGT was comprised of a standard 14-in. tire mounted to a retractable arm. The tire was set with a toe angle of 2 degrees or less and a maintained down pressure. With constant down pressure and a slight toe angle, the sensors inside the hub registered a varying side load dependent on the road friction. Values varied during testing to find the optimum configuration to yield the best definition of pavement conditions at any given time.

In the late winter of 2001, this system (Figure 3) was manufactured and installed in a 1998 2554 International dump truck equipped with a Force America CommandAll 5100 controller and interfaced with a ThomTech Global Positioning Satellite (GPS) system/data collector. Furthermore, a display was added to the truck's front dashboard. The friction readings were provided to the operator via an in-cab display with easy-to-interpret green, yellow, and red light-emitting diode (LED) lights: green indicating good surface conditions, yellow indicating more slippery conditions, and red lights warning of dangerous driving conditions such as ice or

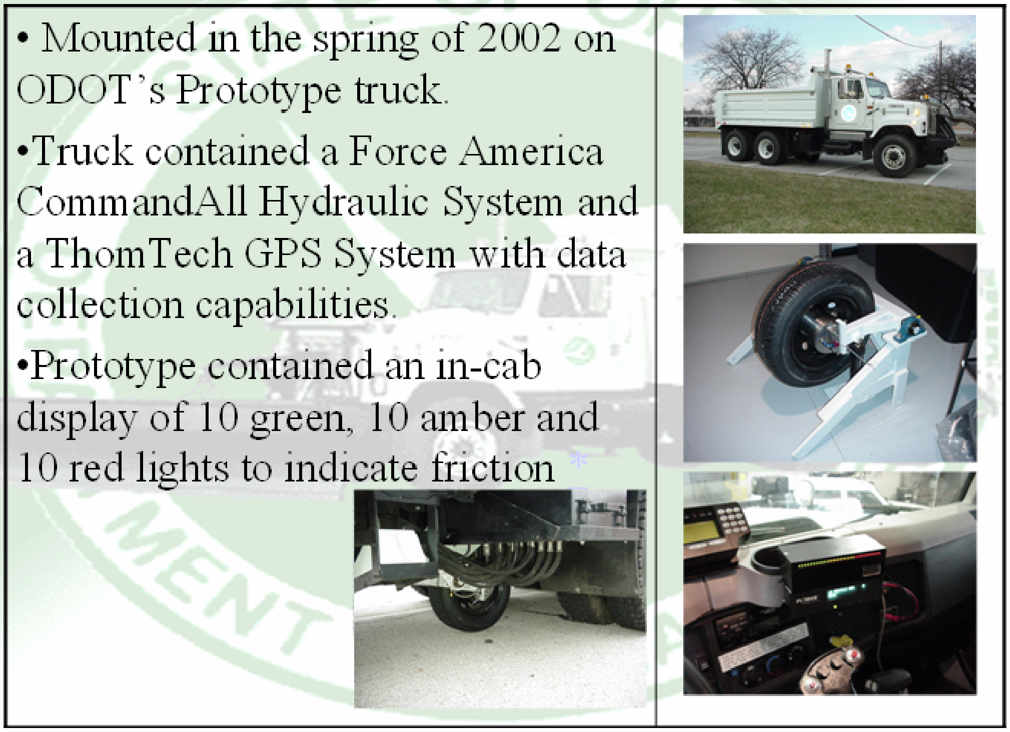

FIGURE 3 Prototype.

snow pack. The display of the indicated friction value was easy to read and interpret wherein more lights equaled less friction (*1*).

In the spring of 2002, ODOT began testing a prototype RGT. The truck was operated by the office of equipment management employees to check the operation and durability of the device. Favorable results were obtained and four additional RGT units were ordered and installed in snow plow trucks in a local garage where equipment management could observe their use and address any concerns, as well as gather and analyze collected data. In the first year of testing, the RGT system performed to expectations. It returned consistent, repeatable results through the summer of 2002 and the winter of 2002–2003. Minor mechanical issues were identified (a seal failure) and corrected, and in the winter of 2003–2004 the four systems in Franklin County were widely accepted by operators as a tool for warning of low-grip areas. Data was collected by each vehicle on data cards for internal post analysis. The instrumentation proved to be a feasible and practical method for measuring pavement surface conditions and providing road user information, thus providing an effective tool for winter maintenance activities (*2*).

TESTING AND REFINEMENT

By the spring of 2004, the project was elevated to another level with the design and development of a tow hitch-mounted RGT for installation on a pickup truck thus eliminating the requirement for a commercial drivers license vehicle. Figures 4 and 5 illustrate the design and attachment. The new design provided greater flexibility and ease of use across all areas of the snow and ice removal operations. It provided the venue for utilization of all available vehicles in the fleet in

FIGURE 4 Tow hitch unit.

FIGURE 5 Close-up of tow hitch unit.

addition to the snow plow units. Intended as a management tool, the system also incorporated real-time data collection and display via a customized website enhanced with both graphic and tabular output. The real time relay of the road surface data coupled with ease of interpretation, created an excellent tool for possible integration into the decision-making process for the snow and ice operation activities.

Field Testing

During the summer of 2004, 12 tow units were deployed at various locations across the state. The RGTs were installed on pickup trucks utilized as road maintenance vehicles as well as those used as freeway patrol units (courteous patrols)—vehicles which log many miles in a day's time. Testing was initiated to operate the units continuously for 1 year to collect road friction data for the purpose of verifying the equipment and instrumentation durability and to confirm and validate accuracy and repeatability of the collected data. Data types collected included date, time, speed, latitude, longitude, road temperature, air temperature, and friction values information.

In addition to confirming durability through the use of high-mileage vehicles, the summer testing parameters included identifying seven individual, straightaway sections of like pavement surface to be utilized for repeatability and accuracy type of testing. By summer's end over 200 truck days of data collection, consisting of nearly 150,000 readings were completed. Numerous readings were collected through repeated travel paths and follow testing (involving two units working simultaneously) and compared to validate repeatability and accuracy within individual vehicles and among simultaneous units. Other variables such as surface condition (wet or dry), pavement temperature, tire air pressure, and tire tread depth were also evaluated. Additional testing was conducted in a controlled environment at the Transportation Research Center and the Ohio State University ice rink to assist in the refinement and validation of the friction measuring indicators. Testing results from the summer activities found the units to be durable and dependable. Reported data was consistent and accurately reflected the pavement conditions.

During the 2004–2005 winter season the same methodology was employed for validating the durability, consistency, and accuracy of the units under severe weather conditions. The tow hitch units were deployed at various locations across the state collecting and reporting real-time data. The snow plow units from the year before were once again deployed using manual data collection techniques. Data and feedback were monitored to validate the usefulness of the friction measurements. Additionally, photographs were included as a visual documentation of measured conditions and were combined with mapping and graphing techniques to provide a thorough representation of actual conditions. Figures 6 to 8 illustrate the deterioration of a pavement section during a typical winter event utilizing this documentation process.

Real-Time Data Collection

To provide a true representation of the roadway surface condition, readings are collected and averaged at a high frequency. The numerical value indicated by the RGT display is arrived through a running average of values on a 10-s cycle. Each 10-s reading is arrived at from the averaging of 100 friction readings per second. In the event the readings indicate ice conditions, the reporting cycle for the readings changes from every 10 s to every 2 s. This shorter cycle

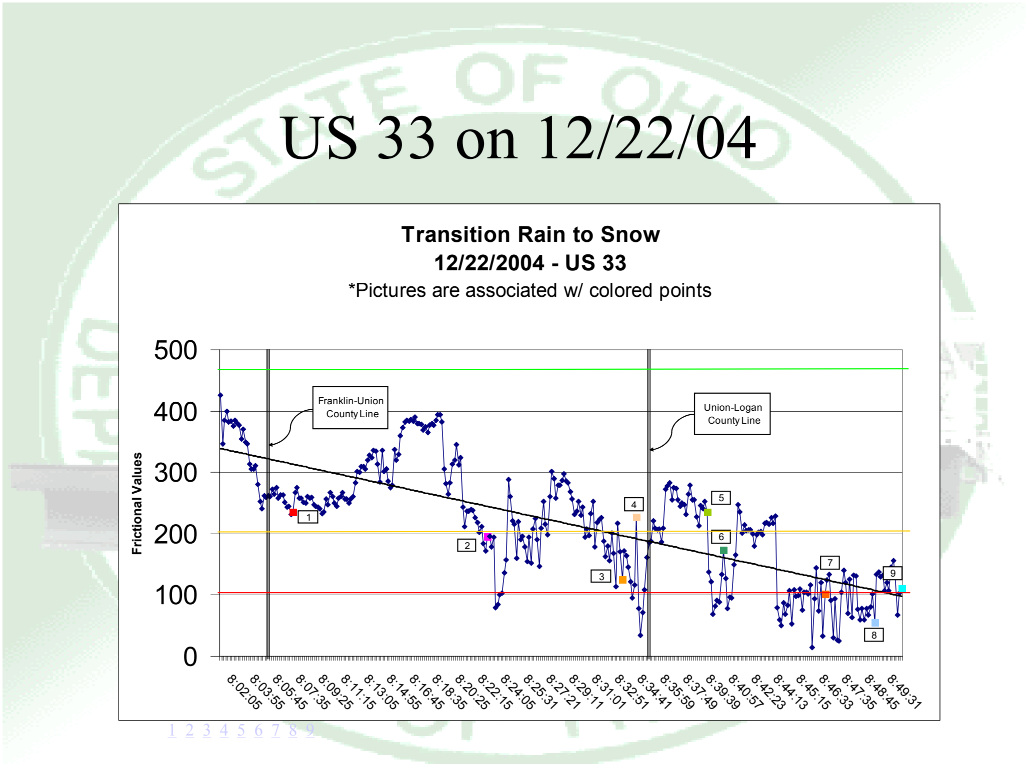

FIGURE 6 Transition graph.

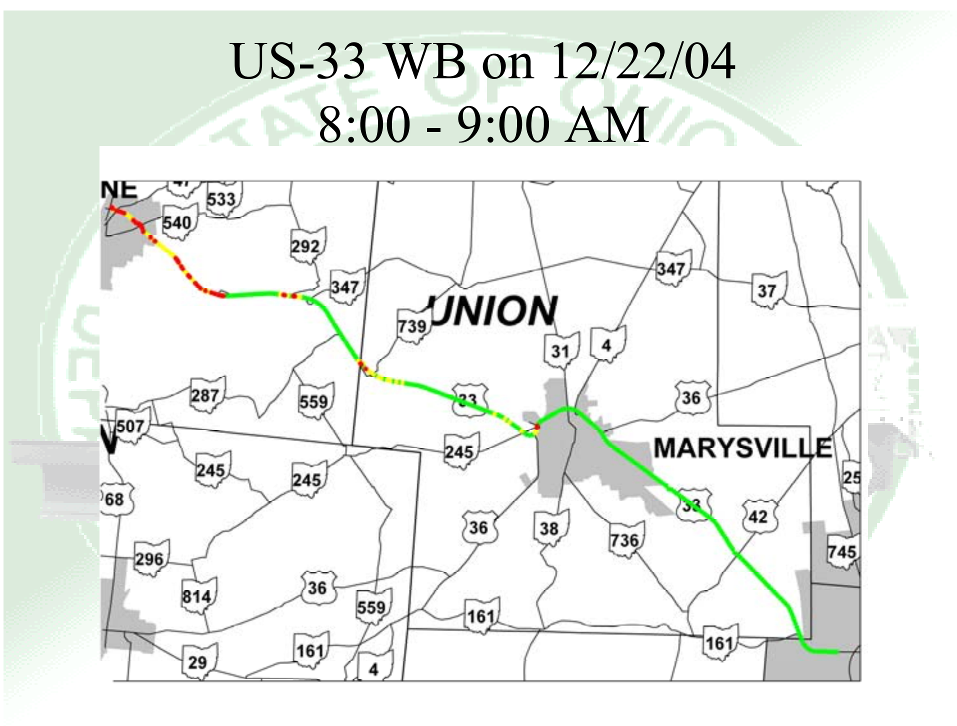

FIGURE 7 Transition map.

FIGURE 8 Photo of transition.

allows for the detection and reporting of shorter sections of ice covered pavements such as bridge decks.

Transmittal of friction data and respective locations in real time from the field to the operations center where critical decisions are made is documented as the most promising scenario for enhancing winter maintenance operations (*3*). This capability of real-time data collection proved to be critical for not only operational decision making but also the management of numerous units. A website developed and managed by ThomTech provided all relevant information regarding general vehicle operation and friction data as captured and displayed for each vehicle. In addition to providing real-time data, the website offered the option of creating a play back of individual vehicle paths allowing for quick analysis of road surface conditions throughout the duration of a winter event; see Figure 9 for a detail of this display option. Units were easily identified and associated information organized through the use of the end user graphics.

Refinement

In addition to miscellaneous mechanical issues associated with project development, results from the 2004–2005 testing provided supporting data to warrant a modification in the mounting position of the friction wheel. Originally designed as a center mount on the underside of a snow plow or a center mount as a tow behind unit, testing yielded an offset design to be a more feasible approach. Mechanical difficulties associated with access and changing of the tire used by the fiction wheel necessitated a design of easier accessibility. Friction measurements by the center design mount frequently were not representative of data associated with vehicle wheelpaths.

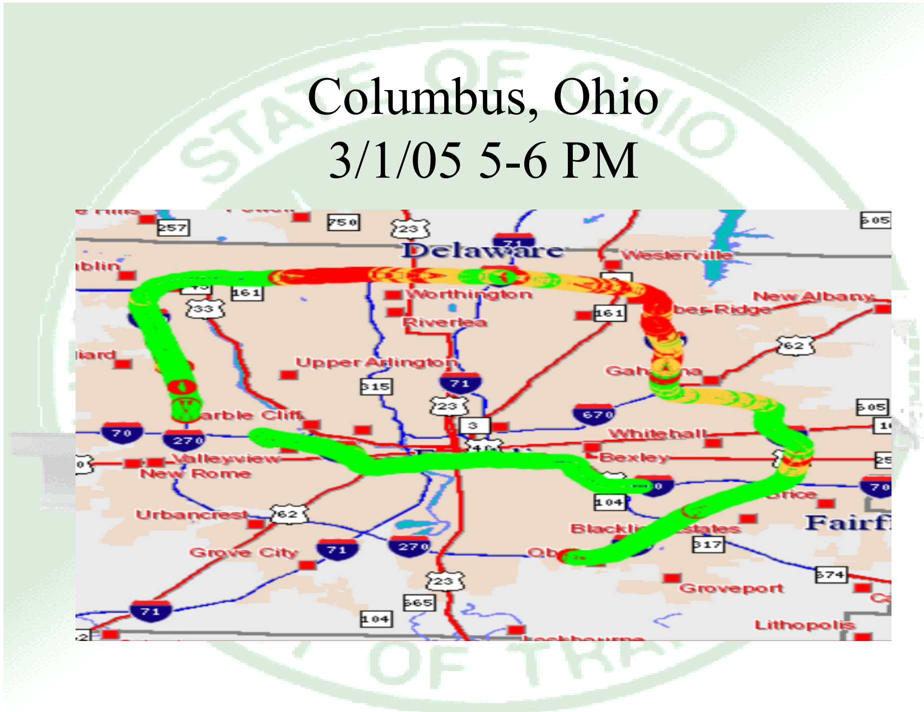

FIGURE 9 Website screen.

An offset version designed to replicate the path traveled by vehicles offered a solution to both areas. The new design, illustrated in Figure 10, was manufactured and installed on both unit types for preliminary testing and evaluation. Yielding good results, modifications were completed for all existing tow behind units and all newly ordered snow plow units for the 2005–2006 season.

Throughout testing and evaluation the scale indicating the numerical rating of the friction measurement has been refined. The current scale creates a linear relationship between force change on the RGT wheel and a predefined numeric scale. This predefined scale uses the value of 100 to represent the friction reading generated on a good smooth, dry surface at 38 F. By comparison, powdered snow without ice reads 52 and the reading on a smooth ice surface is 15. The RGT display uses 30 LED lights of three different colors—red, yellow, or green—to represent the condition of the road surface. The graduation between the three colors occurs on a scale of 100 to 70 representing green, 70 to 50 representing yellow, and below 50 as red (*1*).

2005–2006 DEPLOYMENT

Units will again be deployed across the state for continued testing and evaluation within given scenarios. The 12 existing tow units, all modified to the offset design, will be utilized as a management tool on high-mileage type vehicles. The four existing Franklin County snow plow units will be upgraded to real-time data collection. If resources allow, these units will be modified to an offset version. Several new underbody snow plow units will be installed within one central garage location to test for potential integration capabilities within their snow and ice

FIGURE 10 Offset tow unit.

operations. It is anticipated that a minimum of 24 units, 12 tow behind, and 12 underbody, will be actively deployed by December 2005.

Tentative goals for this season's evaluation include the development of a project management process to ensure accurate equipment use and data collection. The importance of maintaining equipment usability and accuracy are critical not only in the data collection process but also as related to user buy-in and project support. While the acceptance level of the new instrumentation has been positive overall, the potential for rejection and project failure are heavily influenced by the dependability and usefulness of the equipment and associated data. The near transparent application of the units, coupled with the immediate supply of practical and useful information, provides an excellent tool for both operator and manager. Guarding against malfunctions, ensuring accurate and reliable data, and quickly troubleshooting any apparent problems are essential to project success.

ESTIMATED COST

Total cost for an installed RGT unit varies by type of unit and the overall quantity ordered; approximations for the RGT equipment and instrumentation only are one unit at $25,000 per unit or six units at $20,000 per unit. In addition to unit cost there are various costs associated with hydraulics, shipping, installation, and training. There also are additional costs associated with data collection and retrieval and with communications. The average cost for data collection is $2,500 per vehicle for the data collector, the GPS receiver, Nextel modem, and associated hardware.

CONCLUSION

Refinement continues as an ongoing process with evolution of the RGT project. Equipment modifications resulting from user feedback, to allow for ease of use and access, are an important component of maintaining user buy-in and providing a user friendly tool. Website revisions and reporting methods are continuously monitored for improvements to allow for ease-of-use within operations and integration into the real-time decision making process. Short-term mechanical issues such as steering adjustments are also under development to eliminate impacts of slight curves on grip readings; thus creating a higher degree of instrumentation credibility. Mapping options to create a more user friendly display and one to illustrate deteriorated pavement conditions are being addressed internally. As with any emerging technology, obstacles are expected and addressed.

Anticipated outcomes for the project are varied and cover numerous aspects, however major targeted areas include

- Creating a system that detects, records, reports, and disseminates informational data regarding low grip area on road surfaces;
- Exploring integration with other AVL applications and RWIS;
- Providing a process for integration of RGT data into an early alert and advance notification system for:
  - Winter maintenance activities;
  - Motorist alerts, including possible radio and message board alerts–notifications;
  - Ohio Transportation Information System, Ohio Department of Transportation’s website for winter weather condition reporting;
  - Treatment implementation or adjustment; and
  - Performance evaluation and level of service.

REFERENCES

1. Halliday, P. Real-Time Continuous Friction Measurement Has Arrived. *Salt and Highway Deicing*, Salt Institute, Spring 2005.
2. Nixon, W. A. Friction as a Tool for Winter Maintenance. Transportation Conference Proceedings, 1998.
3. Al-Qadi, I. L., A. Loulizi, G. W. Flintsch, D. S. Roosevelt, R. Decker, J. C. Wambold, and W. A. Nixon. *Feasibility of Using Friction Indicators to Improve Winter Maintenance Operations and Mobility*. NCHRP Project 6-14, Transportation Research Board, National Research Council, Washington, D.C., 2002.

PART 5

Maintenance Management, Quality Assurance, and Leadership

Statewide Implementation of a Maintenance Management System in North Carolina

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LACY D. LOVE
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The North Carolina Department of Transportation recently implemented a maintenance management system (MMS) across the state. This effort coincided with the implementation of a new financial management information system (FMIS) to which the MMS is interfaced. The MMS is developed and supported by AgileAssets Inc., and the FMIS is the R/3 system from SAP. The objectives of the MMS implementation included planning based on the condition survey results, programming, and budgeting using ideal, baseline, and dynamic annual plans, resource management and task-based scheduling to support the acquisition of work history at a high level of detail including the linear reference, as well as considerable monitoring and evaluation through numerous reports.

The paper primarily describes the main implementation project and basic operation of the new system, but also offers insights and hindsight based our experiences since "Go Live." The MMS system utilizes data at two major levels. For the strategic planning level, all actual work quantities and expenditures returned from the FMIS are summarized by cost center, county, highway functional class, and budget category. These are used in conjunction with the condition survey results to create internal models predicting the condition of the highway system for any level of spending. The models can then be used to perform incremental benefit cost optimization for various user selected sub-sets of the network and on various budgets to determine answers to an array of strategic planning and budgeting questions. These analyses generate efficient frontiers for cost and level of service and also allow for the creation of annual plans and budgets for field units against which more detailed planning can be performed. These plans can be maintained and monitored on a continuous basis.

At the more tactical level, scheduling and recording of work history takes place at a task level. All actual work quantities and expenditures returned from the FMIS are linked to individual tasks set up in the MMS. These tasks are essentially individual jobs of a specified activity type and at a specified location. The result is that the work history can be queried for any point or segment of a road. This has the immediate benefit of providing up to date, accessible work history for all field personnel but it also provides the ability to make this information available to other management systems. One of the most important is the pavement management system. With regard to the rolling out of the system into production, some of the training and post-roll out support issues are discussed and some recommendations made.

BACKGROUND

North Carolina Department of Transportation (NCDOT) has one of the largest state-maintained road networks in the country with

- 78,615 road miles,
- 158,592 paved lane miles,
- 6,644 mi of unpaved roads,
- 17,756 structures, and
- 78.8 million square feet of bridge deck area.

The system is operated and maintained by 14 divisions divided into 40 districts and 100 counties. There are eight central units that provide policy guidance and oversight.

As early as 1992, NCDOT recognized the need to for a comprehensive maintenance management system (MMS) to help manage the enormous system it is responsible for and the resources that maintain it. In 1994 a steering committee was formed to provide guidance in the development of the strategy to implement such a system. Out of that work a framework was developed that identified the desires of the steering committee for the functionality of a modern MMS. To help champion this effort, a maintenance management engineer was hired in 1993. Along with this position, the department employed a consultant to help lead this effort and to provide technical expertise on the procurement and implementation of a software product.

Based on the efforts of the steering committee, in 1997 the department began the process of developing a request for information (RFI) for a MMS focusing primarily on the functionality of what it should do. A RFI was published and sent to all know vendors of MMS software seeking input on their ability to provide a software product that would meet the desires of the department. Vendors were also invited to demonstrate their product to the steering committee in order for the department to better understand the capabilities of the software and to ask questions about the product. With this knowledge, the department put together a request for proposal in 1999 that consisted of both functional (what it does) and technical (how the software works in the background) requirements.

A team of field engineers was selected to work with the technical team to evaluate each vendor's proposal and in 2000 AgileAssets Inc. was selected as the vendor to install their maintenance management software for approximately 1,100 users.

The project was split into two phases: a reconciliation phase during which the desired business processes were compared to the commercial off the shelf (COTS) software package and desired software enhancements were identified and a second implementation phase. The project started in September 2001 with initial formal end user training being completed in early 2004 for total project duration of just less than 2.5 years.

At the same time as the MMS software procurement was under way, the department also embarked on an effort to develop a maintenance quality assurance program. This effort was spurred along by the state legislative requirement that the department prepare a report on the maintenance needs of the state highway system. The department's Maintenance Condition Assessment Program (MCAP) was developed to survey the condition of the system and use this information to develop funding needs for annual routine maintenance and the annual resurfacing program.

The first step was to establish the most important roadway elements, features, and specific threshold conditions. This was accomplished and outlined by Lacy Love and Timothy Baughman in a paper published in the *Proceedings of the Ninth Maintenance Management Conference* (*1*). The features ranged from pavement condition, through shoulder and drainage features, to mowing, litter pickup, and traffic signs.

With MCAP developed, another key piece of the MMS program was in place to help develop strategic analysis and planning programs based on needs assessment and survey methodology.

PROJECT ACTIVITIES

The major project activities are briefly discussed below:

Project Management

The project was managed by a combined team from the MMS software vendor and an independent NCDOT oversight team. The vendor supplied four permanent core staff on site, including a full-time project manager who was responsible for vendor project management, planning, scheduling, and deliverable submission and approval. The oversight team initially consisted of five personnel with a core team of four remaining for the duration of the project. This team was responsible for deliverable approval and project management with regard to NCDOT information technology procedures and conformance with statewide architecture. The full project team was headed up by an NCDOT project manager.

Creation of a User Familiarization Area

In order to map the COTS software to the business processes desired by NCDOT and identify potential gaps, the MMS software was loaded into an environment with an initial “draft” configuration and an initial data conversion was performed using sample data from a variety of sources.

Identification and Involvement of Subject Matter Experts

Once the MMS software vendor was on site, user interviews were conducted to determine user needs and job responsibilities. From this process, subject matter experts (SME) were identified. These individuals were DOT employees who worked on the project on a part-time basis for the duration of the project. They represented a broad range of DOT functions and experience. The SMEs were involved in interactive demos of the MMS software and helped determine existing DOT business processes and training needs.

Some of the SMEs became the internal champions of MMS and were committed to the philosophy of maintenance management. They were willing to take ownership of the program and motivated to make improvements within the organization. They also became the first super users being able to navigate the system and show others how to find their data.

During the MMS software configuration phase, the training materials for the pilot phase were also developed. SMEs offered opinions on how training should be done and were an integral part of the training philosophy.

Reconciliation and Resolution of Design Issues

During this phase, sessions were conducted in a central vendor training area with SMEs from all levels of the organization including field personnel. These sessions were interactive walk throughs of the MMS software using the user familiarization area (UFA) environment described above where field personnel were given hands-on experience with the MMS software and potential problem areas were identified. Based on these sessions a number of potential enhancements were identified and costs were estimated by the vendor. A subset of these enhancements was subsequently approved by NCDOT for implementation.

Conversion, Interface, and Software Enhancement Development

Conversion was carried out in two stages. As noted above, the first conversions took place to allow for the creation of a UFA and comprised of simply obtaining realistic and familiar data. The final conversion was carried out nearer to the commencement of the pilot phase and was able to utilize some of the newly converted data for the financial management information system (FMIS).

Interfaces were designed and developed by the software vendor to update internal data from external sources. The following main interfaces were set up.

1. Geographic information system (GIS): Routes, sections, and bridges. This was an on-demand interface to update the internal list of maintenance sections and bridges using the latest information (such as urban boundaries etc.) from GIS.
2. FMIS: Labor master list. This was an automatic nightly interface from human resources to update the internal list of employees.
3. FMIS: Equipment master list: This was an automatic nightly interface to update the internal list of equipment.
4. FMIS: Material pricing. This was an automatic nightly interface to update the internal list of materials.
5. FMIS: Work breakdown structure (WBS) account codes and funding levels. This was an automatic nightly interface to update the internal list of account codes together with their current funding levels.
6. FMIS: Transactional data. This was an automatic nightly interface to update the internal list of cost and accomplishment transactions from the FMIS.

Conversion was able to be linked to the interfaces in some cases so that the final conversion essentially entailed an initial running of the interfaces.

Software enhancements were designed and developed by the vendor based on the outcomes of the reconciliation and resolution of design issues activities.

Testing

On completion of the interface and enhancement development, system testing was conducted on both the interfaces and enhancements by the vendor to ensure that the system was ready for the pilot phase. In addition, a user acceptance test was carried out by NCDOT.

Pilot Phase

Two of the 14 NCDOT highway divisions were selected to pilot the program to determine whether additional modifications were needed to the either the system or to business processes prior to statewide implementation. These divisions were also testing the effectiveness of the training philosophy and the training materials. The pilot was conducted in late 2003.

Among the various things the MMS pilot tested were

- User's ability to perform various operations in MMS (planning, scheduling, analysis, etc.);
- Function of new business processes such as scenario analysis;
- Effectiveness of training and training material;
- Help desk support;
- Performance of the computer system;
- System configuration and interfaces with other programs; and
- Response times of the system to the users.

No modifications were needed in the MMS software and only minor modifications were suggested in the training materials.

Training and Rollout

Training was developed as role-based training meaning it was focused on the user's role and responsibilities. Training was segregated into six groups: Raleigh Operations (central units and chief engineer's office), division wide managers, division engineers, district and county maintenance engineers, transportation supervisors, and support staff. To maximize the efficiency of the training and minimize time away from the office central computer training facilities were used to conduct the training. Groups of 12 to 15 people were trained at a time. The software vendor developed the initial training materials.

The original contract specified that upon completion of the pilot, the system would be shut down, modifications made, and other divisions trained. Only after completion of statewide training the system then is turned back on for a statewide "Go Live." At the completion of the pilot, however, management began to question whether the "big bang" approach was most appropriate. This approach would mean long gaps between training and use of the system as well as the loss of data that had been entered into the system by the pilot divisions.

The contract was therefore modified to allow for the system to remain live during the statewide training effort meaning that the system was phased in across the state. This allowed training participants to return to their office and immediately begin using the system. Training was still role based and done in small group settings in computer labs allowing for questions. An issue that was identified immediately was lack of computer experience by the supervisor classifications. These employees are not engineers and for the most part, had little or no computer knowledge. In order for these key managers to be successful, training had to be extended to handle this issue.

The training and rollout to the remaining highway divisions took place from approximately October 2003 through March 2004.

Postimplementation Support

Once initial formal training by the vendor trainers was completed in March 2004, immediate system usage was somewhat sporadic. One problem that was beyond the control of the MMS team was that the departmentwide implementation of the new FMIS occurred only 10 months prior to the MMS Go Live. Since the learning curve for that system was still underway, users were reluctant to attempt to use both systems. Other problems at Go Live included lack of computers on supervisor's desks, and users having to first log in to the Citrix Server (a special server running MMS application that allows client users to access the software through the web) and then again into the MMS necessitating two sets of user names and passwords. All these things compounded to produce a rather slow ramp up in the use of the system.

To overcome these issues, the NCDOT MMS team began to deploy various strategies.

User Groups

User groups were developed for various functional classifications. Initial groups established were the divisionwide units (only 14 statewide) where the logistics of bringing everyone together from across the state were easier. The first group convened was the road oil supervisor's user group. User group meetings included some structured time on the computer doing a function in MMS such as inputting the annual dynamic plan or completing tasks or service requests. Part of the time was a more open format where the participants would have a chance to bring their concerns to light and talk about them as a group.

This approach worked well in small group settings where there were enough computers for all participants to be engaged. Large groups such as the county maintenance engineers and transportation supervisors were entirely too large (approximately 350) for user group meetings to be effective.

Technical Trainers

To attempt to cover the larger groups such as the county maintenance engineers, three technical trainers were hired to visit the various field offices and meet one on one with users to identify their needs. During these visits the trainers would demonstrate the benefits of MMS to the users. They also were able to identify some enhancements that could be implemented to aid integration between MMS and the FMIS software (SAP R/3). These field trainers proved to be invaluable for helping users become familiar with both systems and use them as a seamless, integrated whole.

In July 2005, the NCDOT field technical assistance portion of the MMS project was contracted out. This contract was expanded to five technical support personnel on a full-time basis who rotate across the state visiting offices and offering hands on tutorial assistance, as well as identifying trends among users and developing functional specific user reports. Some of the personnel were the same as those originally in place and so were able to provide considerable continuity. These personnel are still performing this role at the time of writing and have proven to be a very valuable resource to the project with system usage improving continuously and over 2000 user specific reports being developed to date.

SOFTWARE OPERATION

The MMS system utilizes data at two major levels. For the strategic planning level, all actual work quantities and expenditures returned from the FMIS are summarized by cost center, county, highway functional class, and budget category. These are used in conjunction with the maintenance condition assessment survey results to create internal models predicting the condition of the highway system based on various levels of spending. The models can then be used to perform incremental benefit cost optimization for various user selected subsets of the network and on various budgets to determine answers to an array of strategic planning and budgeting questions. These analyses generate efficient frontiers for cost and level of service (LOS) and also allow for the creation of annual plans and budgets for field units against which more detailed planning can be performed. These plans can be maintained and monitored on a continuous basis.

At the more tactical level, scheduling and recording of work history takes place at a task level. All actual work quantities and expenditures returned from the FMIS are linked to individual tasks set up in the MMS. These tasks are essentially individual jobs of a specified activity type and at a specified location. The result is that the work history can be queried for any point or segment of a road. This has the immediate benefit of providing up to date, accessible work history for all field personnel but it also provides the ability to make this information available to other management systems. One of the most important of these is the pavement management system (PMS).

STRATEGIC LEVEL OPERATION: PLANS AND ANALYSIS

In keeping with the AASHTO-published *Guidelines for Maintenance Management Systems* (*2*), NCDOT essentially required functionality for planning, programming and budgeting, resource management, scheduling, monitoring, and evaluation.

Analysis scenarios in the MMS software represent the beginning of the planning phase. The primary objective is to try to find the mix of work (in terms of how much of each work function to perform and where to perform it) that will most efficiently meet the strategic objectives.

Users ultimately need to answer two main questions:

- What will it cost to reach a LOS target?
- What LOS can be attained with a fixed budget?

A management user thus needs to be able to set-up and run an analysis scenario to give the most cost-effective way to attain a performance goal (specified in terms of a maintenance index introduced below). A field user needs a work plan to maximize the maintenance index subject to budget constraints.

The inputs for setting up and running an analysis scenario are:

- Work accomplished: The actual expenditures per county, road system, and activity.
- Condition survey results: The percent of assets failed per county and road system.
- Inventory summary: The quantity of each asset type per county and road system.
- Maintenance index: A weighting of the importance of each defect. Multiple indices can be defined.

Calculating the Value of an Index from Survey Data

In order to measure LOS for a network or portion of the network, the following steps are needed.

1. Define the activities that are performed.
2. Identify the reasons they are performed in terms of what particular deficiencies (called "defects") they are correcting.
3. Identify the overall objective(s) for the maintenance department (e.g., safety and serviceability).
4. Determine how important each defect is within each objective.

This is essentially the process of creating one or more maintenance indices. Since multiple indices can be set up it is possible to subdivide the analysis into multiple parts. In North Carolina, separate indices are defined for each of the main road systems:

- Interstate,
- Primary paved,
- Secondary paved, and
- Urban.

Once an index has been specified in terms of weights for each defect, the index value for that index is calculated as follows. The surveyed "percent failed" values (*1*) for each defect in the index definition are first weighted by the inventory. The resulting "weighted percent failed" values (one for each defect in the index) are then each subtracted from one to give "weighted percent passing" values. These values are finally multiplied together to obtain the final index value. Because of this multiplication, the overall index is therefore always less than the average of the individual values. Having a multiplicative index also does not allow bad results for individual weighted percent failed values to go unnoticed since a single low value will pull down the whole index.

Generating the Total Index Value Versus Total Cost-Efficient Frontier

Overview

After establishing the procedure for calculating an index or LOS value, this can be used in the generation of an optimum curve giving the best attainable index value for a specific funding level or, conversely, the minimum funding level required to sustain a certain LOS or index value. This curve is called an efficient surface or efficient frontier (*3*). This exactly matches the chart shown in Exhibit 3 of the AASHTO *Guidelines for Maintenance Management Systems* (*2*) which is a plot of LOS versus funding needs. Using the optimization analysis, efficient frontiers can be generated for any portion of the road network for any specific criteria as defined in the maintenance indices. As noted previously, four separate indices are defined for North Carolina. These are used to define four separate efficient frontiers: one for each road system. At this stage each represents LOS with respect to a combined safety–serviceability index.

Individual Models

To create this efficient frontier curve requires a great many individual component models: one for each defect on each road system, in each county (currently 21 x 6 x 100 = 12,600 individual models in North Carolina) as shown in Figure 1. Each one of these has a similar form in that it gives the cost for any condition level for the defect.

The efficient frontier is created by taking the best condition increase per dollar (weighted by the inventory and index weighting) from each curve in turn and slowly moving up the main curve until the specified target (whether an index or a cost–budget target) is reached. In this way some money may be put into primary paved system guardrail in Forsyth County for a while, then some money put into high shoulders until the return per dollar drops off, after which it may become cost-effective to put more funding into guard rail again.

Linking Costs and Condition by Linking Work Functions with Defects

As discussed above, the MMS software creates a separate curve or model for each defect on each road system, in each county. However, in order to be able to do this, the system needs to know how much is currently being spent on each defect. This is accomplished by defining for each work function, the proportion of effort going towards each defect.

Using the Efficient Frontier

The efficient frontier can now be used to answer the two main questions:

- What will it cost to reach a LOS target?
- What LOS can be attained with a fixed budget?

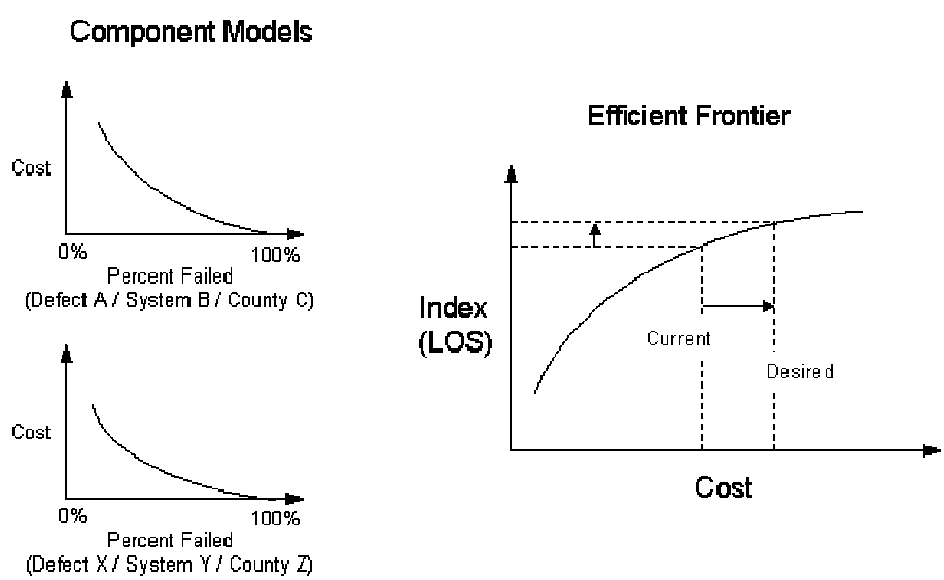

FIGURE 1 Component models and efficient frontier.

Once the method of generating the optimum curve has been established, a point can easily be identified along it by specifying a cost or LOS target. For instance, if the best mix of work to reach a specific maintenance index is needed, the target is an index value. The resulting point not only gives the expenditure necessary to maintain that target but also gives a mix of work, including how much of each work function should be performed on each system in each county that makes up the scope for the analysis. This is because each point on the main curve represents a certain point on each and every individual component curve as discussed above.

Any number of separate efficient frontiers can be generated and stored. This gives considerable flexibility to the agency since analyses can range from a statewide analysis (using a single general index), to individual analyses for additional sums of money, or specific areas such as drainage or traffic control devices. A logical use of the scenario analyses is to generate an efficient frontier for each budget. Because of the way funds are allocated in North Carolina, NCDOT management are currently concentrating on running one scenario analysis per highway division for the primary and urban road systems and one analysis per county for the secondary road system.

Evolving Use of Plans and Analysis Results

Of course, optimization analysis results are useful but they are theoretical and subject to limitations. Also, unless every work function has been linked to a survey defect, some work will fall completely outside the realm of condition related optimization analysis. The MMS software allows users to transfer this information from the analysis results into a workable plan.

The ideal situation, then, is that a user can take their analysis results, import these into a plan and then manipulate, adjust and supplement them as needed.

The general concept in North Carolina is as shown below and falls into a number of basic steps.

1. Run analysis scenarios based on index targets.
2. Use these to create ideal plans. (These are plans that aim for a particular LOS with the assumption of unlimited funding.)
3. After appropriations, run similar scenarios based on the budget constraints from the appropriations. (Primary and urban money per division and secondary money per county.)
4. Use these to create a baseline plan that is also the initial dynamic plan. (Baseline plans are plans that are set at the division level at the beginning of the fiscal year. Dynamic plans are the plans maintained by the individual field offices which change during the year as circumstances change.)
5. Use the dynamic plan as a working plan that can be continuously adjusted and updated throughout the year.

Users do not have to start with optimization analysis but have the ability to import previous work, other plans or start from scratch. Therefore, while the optimization analysis provides a good recommendation, considerable flexibility is allowed.

TACTICAL LEVEL OPERATION: TASKS AND SERVICE REQUESTS

At the more tactical level, the actual work in the field is defined and recorded in terms of tasks and service requests. Tasks are the basic jobs undertaken in the field and are vital to the system. Service requests are optional and act either as project containers for jobs of different work functions, or provide a to do list.

Tasks (Work Orders) and Service Requests

Service requests are typically defined as small projects. They show the type of work that needs to be performed and the specific location where the work is to be performed. The requests are analogous to a to do list. A user specifies the location by designating a maintenance section and a start- and end-mile point within the limits of the maintenance section. In addition to the location, the estimated quantity of work required may be entered.

Although more often designated in terms of type of work, a service request may also be defined as pertaining to a certain defect (for example, low shoulders).

Tasks (also called work orders) are similar to service requests except that they are assigned to a specific work function and can be assigned to a responsible person, such as a supervisor or crew leader. A task can thus be passed from one responsible person to another in a form of workflow depending on procedural requirements. In addition, a task may be scheduled (assigned begin and end dates). Task location and estimated quantity are specified based on the work function. Finally, tasks are assigned to a WBS element (account code) so that charges booked against a task are ultimately booked against an account code when they are complete. Some of the main items stored for a task are

1. Task number,
2. Service request number (if applicable),
3. Work function (activity) and planned quantity,
4. Supervisor,
5. Scheduled–actual start and end dates,
6. Status,
7. Location (route and begin and end milepoints, bridge, etc.),
8. WBS element (account code), and
9. Actual work quantities accomplished and labor, equipment, material, and other costs (returned from the FMIS through the interface).

Actual charges are linked to tasks in much the same way as labor, equipment, and materials charges are assigned to an account code. In fact, the MMS task number has been set up as part of the account code block in the FMIS. Whenever cost transactions are made in the FMIS, a task number can also be entered in that system so that the charges associated with that task are accumulated in the FMIS and will be transferred back to the MMS software. The most common way of recording transactions against an account code is through North Carolina’s FR1101 timesheet form. This is where hours per employee and per unit of equipment are recorded daily and where daily work accomplishment quantities are entered into the FMIS.

FMIS Transactional Interface

Much of the financial information contained in the MMS system is provided through an interface with NCDOT's FMIS where the MMS task number is an integral part of the FMIS account code block.

The most detailed FMIS interface is thus the transactional interface through which all FMIS transactions within a predefined scope are passed back continuously to the MMS (regardless of whether or not they have a task number attached to them). This allows the MMS system to maintain accurate cost information (based on the final actual audited costs from the financial system where any and all adjustments are made, rates applied, and overheads added) for optimization analysis purposes and also allows actual expenditures to be compared to those planned in MMS. Another advantage of this method of obtaining actual financial transaction information is the degree of independence between the two levels of planning and tactical recording in terms of tasks. This independence allows full planning to be carried out by mid to upper-level management, without necessarily depending on complete and accurate task information being recorded at all times by individual field supervisors across the entire organization.

Evolving Use of Tasks

Although it is recommended that tasks be created for all work performed on the road, there are three main purposes for creating tasks in North Carolina.

1. Establishing a road history: A road history can be useful for a number of purposes ranging from future use by pavement management personnel investigating the total amount spent on a certain road section for certain work functions, to investigating a citizen's request for maintenance.
2. For scheduling purposes: Tasks can be very useful purely for scheduling purposes when tasks are entered representing blocks of time to make up a crew schedule. When used only for scheduling purposes, tasks need not be location-specific necessarily. These tasks can be used (with optional assignment of individual resources) for pre-printing timesheets.
3. To facilitate time entry: A task is needed if time is to be entered as day cards in the MMS system.

In order to ease the transition, NCDOT management has purposefully not prescribed use of the system to a high level of detail and has rather set some basic guidelines in terms of criteria such as proportion of total expenditures recorded. This approach has worked relatively well but relies heavily on monitoring use of the software (discussed below) and postimplementation support personnel visiting individual maintenance yards and discussing the specific goals of middle management in the field. As a result of the policy however, field users who are most actively using the MMS are doing so because of a high level of enthusiasm resulting from them getting what they, rather than just central management, want out of the system.

The main goal for use by the field units in North Carolina is to accumulate a road history by entering work accomplished as tasks in MMS. This is useful for a variety of reasons, both from the stand point of central management (for instance the average expenditures per mile can be calculated and used by the pavement management unit or central management to identify problem areas, performance of specific projects and products can be analyzed, etc) and the field personnel themselves (for instance they can readily answer questions from elected officials regarding when certain work was accomplished or capture site specific costs during disasters such as hurricanes for FEMA).

Since the majority of the more than 1,100 named users are field personnel involved with inputting of tasks, users' computer skill levels varied considerably and use of MMS has evolved over the past 18 months. Before being able to effectively capture tasks, therefore, field support and help desk personnel needed to concentrate initially on ensuring users could log in to the system and deal with common problems such as forgotten passwords and user specific technical issues. Once users got comfortable logging in, the next push to encourage users to enter tasks for a large portion of their work could begin. Initially users were just encouraged to enter tasks for their work accomplished and close them when work was complete. Later, the accurate capture of cost information was encouraged by ensuring task numbers were entered in the FMIS on all applicable timesheet, materials, and contract invoice transactions. Because of the parallel implementation of the new FMIS, the entering of MMS task numbers on transactions in the FMIS as part of the account code block was not well defined in the FMIS training and was not covered in depth in the initial MMS training. Training on the dual uses of the FMIS and MMS was therefore the responsibility of the field support personnel.

Since the pilot in 2003, expenditures being associated with tasks in the FMIS through the account code block have grown markedly and will substantially exceed $100 million in the calendar year 2005 as shown in Figure 2.

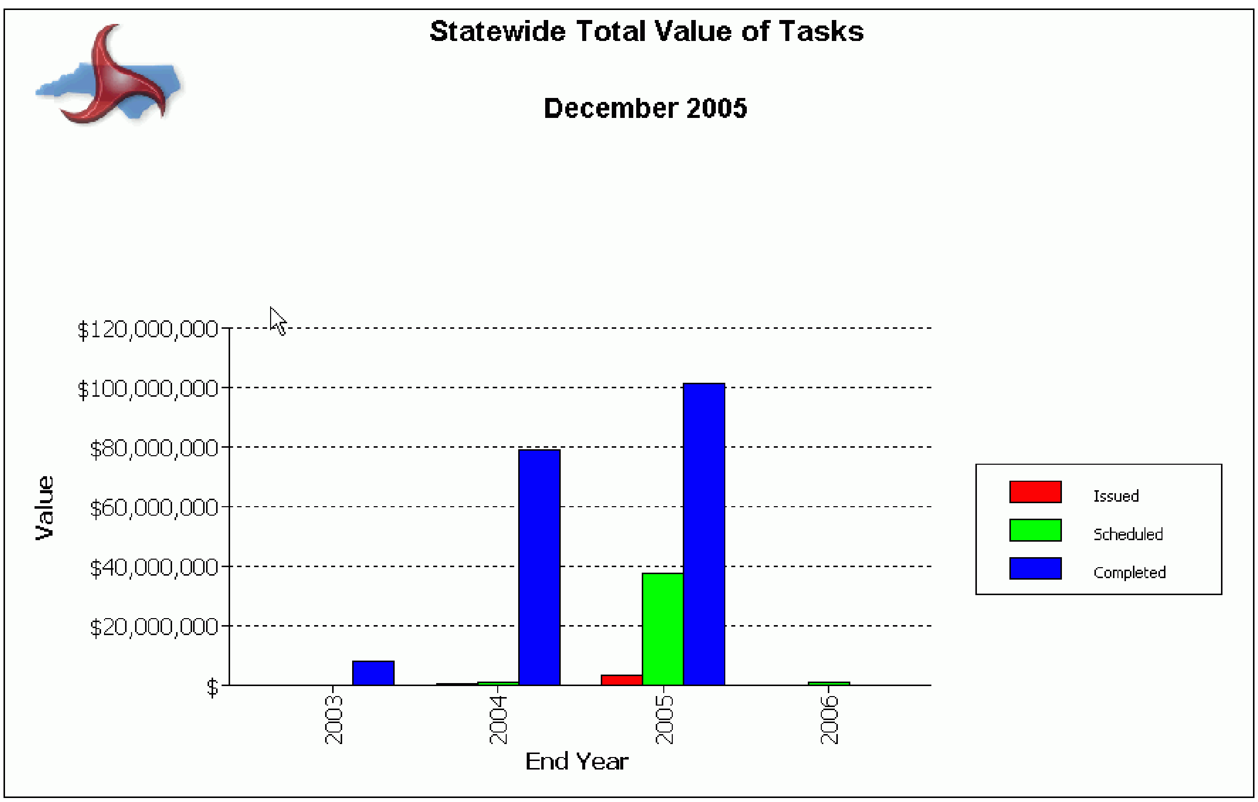

FIGURE 2 Statewide total expenditures associated with tasks.

Now that a considerable portion of all relevant expenditures are being captured, the current area of concentration is more accurate capture of task location. Currently tasks are located at a maintenance section level but many users are starting to capture more exact milepoint locations. This is already prevalent among the agency's chip sealing units where relatively accurate begin and end points for surface treatment work are captured, and to a lesser extent, traffic departments for striping but is becoming increasingly used at county yards for work on specific items such as cross-line pipes.

With regard to the goals of scheduling and time capture, a certain amount of scheduling is currently being performed in the MMS, especially by the agency's chip sealing units. Because the FMIS is currently the entry point for timesheet information, the MMS is not currently used for the capture of this information and this is typically captured directly into the FMIS and passed back to MMS through the interface.

MONITORING AND EVALUATION OF SOFTWARE USAGE

As noted previously, whether or not and what portions of MMS usage are mandated as compulsory is an evolving aspect of MMS usage in North Carolina. In our experience it was very useful to have enough flexibility not to have to mandate complete and total use immediately. This mitigates users against feeling the software is being forced onto them, reduces the potential for friction and encourages enthusiastic and progressive users. Nonetheless, in order to engender a certain amount of momentum and realize the potential of such a system for improving overall efficiency and cost savings, it is necessary to give certain guidelines and monitor each administrative units use of the system continuously.

In order to monitor the use of MMS a number of objectives were identified and associated reports set up. These were as follows:

- Metric Report 1: Total funding planned per administrative unit;
- Metric Report 2: Count of tasks per administrative unit;
- Metric Report 3: Proportion of total expenditures associated with tasks per administrative unit; and
- Metric Report 4: Count of scheduled tasks per administrative unit.

The first metric is designed to monitor the extent of planning of allocated funds. Divisions are required to enter allocations for each administrative unit into their baseline plans. The individual administrative units then use this information to create dynamic plans.

The second and third metrics measure general task usage in terms of a simple count as well as a measurement of the proportion of expenditures associated with tasks. The latter is possible since *all* expenditures are returned to MMS from the FMIS. If the individual transaction has been associated with a task in the FMIS, that transaction will then be attached to the relevant task in MMS. This is possibly the most used metric and identifies administrative units having problems as well as those who are doing well. For instance, the bituminous operations (road oil) units are entering tasks for approximately 70% to 80% of their total expenditures.

The statewide proportions per month are shown in Figure 3. This highlights two things: first that the average proportion of total expenditures associated with tasks is around 25% and second, that the proportion changes seasonally. The fact that task usage is not as high as it should

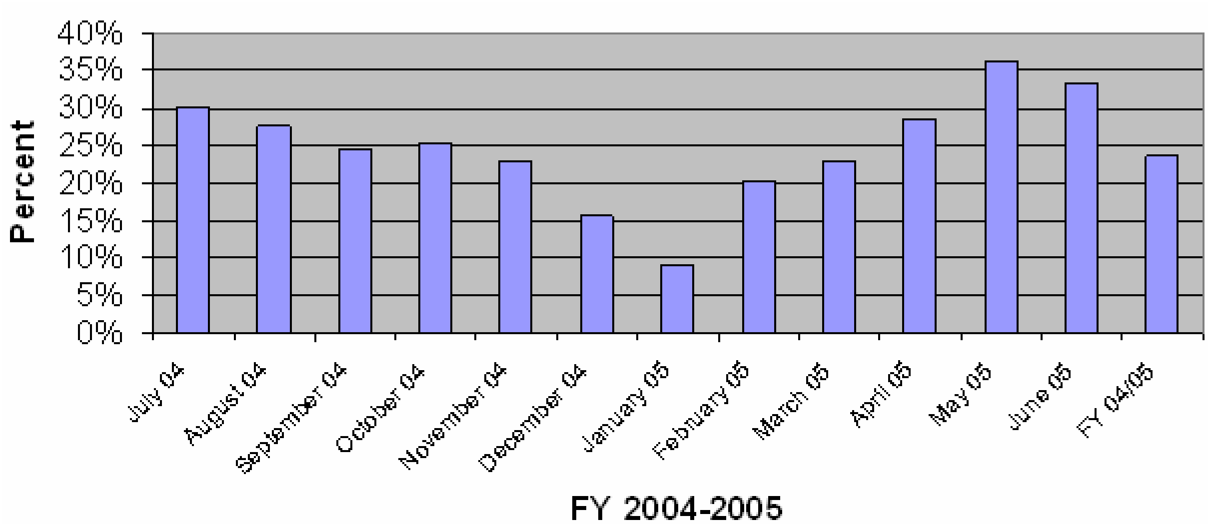

FIGURE 3 Statewide proportion of expenditures associated with tasks.

be, especially amongst county maintenance yards, highlights the fact that their work is a lot more varied and they tend not to capture functions such as dead animal and litter pickup, as well as work around the yard. Routine work like mowing also tends not to be captured since there is little uncertainty about schedule, quantity, and cost. Also, overhead is typically higher in these units where more support staff and supervision staff are needed and a higher proportion of the work is not directly road related.

The seasonality of the proportion is also interesting and distinctly reflects the higher expenditures during the summer months where the amount of road related expenditure is higher generally, and the rate of expenditure is higher due to higher proportions of material expenditure (labor and equipment expenditures stay more constant).

In addition to general monitoring by upper management, evaluations of each administrative unit prior to and after visits by field support are used to measure success of field training visits.

The general philosophy continues to be to mandate a certain level of usage but also encourage users who show interest and trust that these users will have the effect of encouraging others to copy and follow suit.

LESSONS LEARNED

There are many lessons to be learned from any software application implementation. One of the things that was invaluable to the success of this project was the establishment and hiring of a maintenance management engineer whose primary job responsibility was to oversee the effort. That person, in conjunction with the oversight team, provided the guidance and day-to-day administration of the project that is needed for a successful implementation. They not only provided hands-on support to the software vendor, but also provided assistance in preparing the acceptance documentation for the vendor's work progress and payment. In North Carolina there are a variety of reporting requirements for any state agency's software procurement and implementation and the oversight team was assigned the responsibility for preparing these documents. For any agency contemplating implementing a MMS, it is suggested that appropriate staff be dedicated to the effort.

While the department did anticipate and plan for specific activities and processes to occur during the implementation and training phase, it underestimated the impact of the effort. One such gap was the absence of any formal business processes or business rules for how maintenance is accomplished at NCDOT. The vendor was able to overcome this deficiency through the SMEs; however, the implementation may have been easier if our business processes had been mapped out. Another unanticipated impact was the parallel FMIS implementation and the interface issues that created. Since the FMIS system was being designed and configured at the same time as the MMS, it was a challenge to solidify the data structure and needs of the two systems since they share common data elements. Another underestimated impact was the change in the way the department functions. Any major change to the way an agency operates its business should be managed. People do not like change and will resist it at all costs. This resistance needs to be overcome through a multilayered approach. Part of the change management process should include a plan to manage expectations of all involved. While upper management believed that users would readily take to the system that was not the case. At the same time users were frustrated not only with MMS but also with the FMIS. These very different expectations led to even more frustration on both parts and it was only after several meetings and the hard work of the technical support staff that any headway was made on this issue.

The need for technical support following go live can therefore not be overestimated. Technical support of the field users is critical in any implementation and, because of the additional challenge of implementing a completely new FMIS almost in parallel with the MMS implementation, this postimplementation field support was especially important.

Any initial formal training can only be of relatively short duration. Continuing field support, with visits to individual maintenance yards well after initial Go Live, enables users to be introduced to the "what's in it for me" aspect at their own pace and based on their specific problems. With continuing field support, users can increase their knowledge of the system more slowly. They may learn the initial basics in terms of a set of steps as to what can or should be accomplished initially. However, if they can incrementally learn additional aspects by both peer-to-peer exchanges as well as managed field support, their knowledge can mature into a more thorough understanding of the system itself as opposed to just how to perform certain operations. Once this understanding is established along with the accompanying familiarity, many (though not all) users start using the system for innumerable purposes unforeseen by the trainers or original designers.

Technical support needs to be flexible due to everyone's different levels of education, skill, and motivation. Assessment of the current situation at an administrative unit by the field support personnel prior to a visit is very helpful. Being able to customize reports for individual users and ensure that they are getting enough of what they want and need out of the MMS is vital to justify the necessary input of data.

Support of MMS by middle and upper management is vital, even if they do not routinely use the software themselves. Where upper and middle management openly support MMS, units are doing well.

The use of a large system such as MMS needs to be seen and managed as an evolving process. Improvements to the system come from many different sources. Records of requests from users for changes help to see how use of the system expands. Staying in touch with the users is vital to long term growth and use of the software.

Next Steps and Strategic Goals

In general, the overall comfort and skill level of the software user community should continue to be monitored and improved. Continued enhancements to reports as well as the software itself will be made as field personnel continue to adapt their overall management style and culture.

Planning and analysis is one of the next areas of the software that will be emphasized. Part of the cultural change within NCDOT is the aspect of planned maintenance versus reactionary maintenance. Field offices have been accustomed to spending their allocations with no thought for is this the best use for those funds. With tight budgetary constraints in place, local engineers are beginning to more closely monitor where funds are expended. This has led to a strong interest in analyzing the most effective use of available funds.

Along these lines the level of detail of the condition surveys will be increased to support planning and optimization analysis at the county level in MMS as well as support the new performance based management initiative currently being undertaken by the department.

A project to pilot the use of handheld devices for the capture of task and time information is currently being initiated at the time of writing. The transition to the use of handhelds will potentially revolutionize the use of MMS since capturing task information, with the actual location using Global Positioning Satellites (GPS), at the time the job is done will be considerably easier. The current push for more accurate location information will be greatly aided with the introduction of handheld devices for data collection where GPS coordinates will be logged. Currently the FMIS is the sole entry point for timesheet information. However, if the capture of this information is proved to be feasible the use of handhelds likely will also increase the use of tasks for scheduling (scheduled tasks are uploaded to handhelds), and will almost certainly increase the use of tasks in the capture of timesheet information.

The implementation of an enterprise-wide linear referencing system is already enabling detailed MMS information to be plotted and mapped in GIS. This will be promoted and should gain momentum with the introduction of handheld devices.

In 2004 the department's Board of Transportation approved the long-range statewide multimodal transportation plan which lays out a framework for investment strategy over the next 25 years. This visionary document places an emphasis on preserving, maintaining, and operating the vast state highway infrastructure. This coupled with the department's business plan will be used to further refine how the department measures its success in taking care of the state's highway system. Using these documents, the department is in the process of developing performance measures, performance targets, and LOS for each of the department's assets against which performance will be tracked. With these in place and using the MMS program, the department can move toward a performance-based budget and give the field offices and managers the freedom and greater flexibility to develop and implement their own specialized plan to meet the pre-defined performance target.

Using MMS as the hub, the department is also pursuing the implementation of other management systems to further enhance the tools available to the operational units and divisions. The department has recently employed AgileAssets Inc. to implement their PMS (designed and configured to meet NCDOT's needs). This system will be interfaced with our current MMS (*4*) and will result in salient maintenance information being passed seamlessly and continuously to the PMS for use in long-term pavement optimization analysis. Surface treatment and thin overlay plans (currently largely managed and implemented by maintenance) generated in the PMS will in turn be able to be passed back to the MMS. The implementation of the PMS may result in many of the pavement-related activities being removed form the maintenance optimization analysis and planned under the PMS. With the two resulting efficient frontiers (one for pavements and one for other roadside assets) being available, these will be able to be recombined later in a trade off between these two general asset classes.

The department is also currently working to incorporate a signal management system that was developed internally as well as conducting preliminary investigations into the availability of a bridge management system. As each system comes on line, it is a firm commitment that they all interface with one another to share the exchange of data across systems to prevent the stand alone or "stove pipe" systems of the past.

REFERENCES

1. Love, D. L., and T. B. Baughman. Implementing North Carolina Department of Transportation Program for Maintenance Assessment and Funding Needs. *Proc., 9th Maintenance Management Conference*, TRB, National Research Council, Washington, D.C., 2001.
2. AASHTO. *Guidelines for Maintenance Management Systems*, Final Draft, May 2004.
3. Pilson, C., W. R. Hudson, and V. Anderson. Multi-Objective Optimization in Pavement Management Using Genetic Algorithms and Efficient Surfaces. *Transportation Research Record: Journal of the Transportation Research Board, No. 1655*, TRB, National Research Council, Washington, D.C., 1999, pp. 42–48.
4. Pilson, C. C., and J. Corley-Lay. Integration of Maintenance and Pavement Management Systems in North Carolina. Presented at 6th International Conference on Transportation Asset Management, Kansas City, Mo., 2005.

Synthesis of Measures for Highway Maintenance Quality Assurance

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Many transportation agencies are dealing with constrained budgets and reduced funding for maintenance by establishing formal programs to evaluate maintenance priorities. One approach is to relate highway maintenance to highway performance through maintenance quality assurance (MQA). MQA programs help decision makers understand maintenance conditions, set priorities, and document the relationship between dollars spent and outcomes. There are guidelines to assist agencies in the creation of MQA programs, but few resources to guide the selection of quantitative measures. This paper presents a synthesis of MQA measures used by 26 state transportation agencies.

States are interested in communicating with others about using MQA programs to justify budgets, account for maintenance expenditures, and evaluate spending and allocations for maintenance. This paper presents a set of terms essential to MQA. These terms define the relevant concepts of MQA and are used to facilitate discussion about maintenance measuring.

By considering a terminology and synthesis of the measures used in MQA, agencies can create better MQA programs, improve existing programs, improve dialogue, and target future development of MQA programs.

INTRODUCTION

Maintenance quality assurance (MQA) is a process that uses quantitative quality indicators and statistical analysis to assess the performance of maintenance programs. Quality in maintenance is not new; it was an important factor in the maintenance management systems movement of the 1960s (*1*). In recent years, the notion of quality has gained renewed momentum as maintenance program managers face new challenges to justify budgets and account for maintenance expenditure allocations and decisions (*2*). The development of MQA programs comes in the midst of a national shift towards using measures to manage government and budgets. Many of the systems are designed to take advantage of opportunities for system-level decision making afforded by modern data collection and management technology.

Well-maintained highways are important in meeting the nation's needs. Since the completion of the Interstate Highway System there has been only a marginal change in highway lane miles. Much of the emphasis of state departments of transportation has now turned to highway reinvestments through federally funded rehabilitation, reconstruction, and replacement programs. During the same time, maintenance budgets have failed to keep pace with the significant growth in vehicle miles traveled on the highway system.

MQA is a term being used to cover a broad scope of agency programs for managing and monitoring the effectiveness of maintenance operations. The scope includes level of service

(LOS), maintenance performance measurement, maintenance condition assessment, and maintenance accountability among others. Examples of such programs include MAP in Washington, AMMO in Montana, Maintenance Condition Survey in North Carolina, and Compass in Wisconsin.

There are guidelines available to assist in the creation of an MQA program. *NCHRP Report 422* is an implementation manual that guides highway agencies in the development and application of a MQA program (*1*). *NCHRP Report 511* provides guidance on how to evaluate and improve performance through "customer-driven benchmarking" (*3*). Customer-driven benchmarking involves the establishment of LOS or threshold values as a means for continuous improvement in maintenance management.

There is little guidance on the selection of quantitative measures for maintenance quality. States tend to tap into peer networks as the best resource. To facilitate this networking, a national MQA peer exchange was held in Madison, Wisconsin, in October 2004. The event brought together transportation officials from 35 U.S. states and Canadian provinces to share information and ideas on current MQA programs and practices. An MQA documents and materials library (http://www.mrutc.org/outreach/MQA/library/) was created by organizing the MQA program documents submitted by many of the agencies that participated in the peer exchange (*4*).

The participants of the national MQA peer exchange defined a national agenda for MQA program development (*4*). Among the agenda items is a synthesis of commonly used measures for MQA. This paper responded by presenting a synthesis of measures used to quantify maintenance condition. The primary source of information is the comprehensive collection of field guides, rating manuals, reports, and field checklists collected from the agencies participating in the national peer exchange.

Cross-agency efforts to facilitate the development of MQA programs are inhibited by the lack of a commonly understood set of terms for communicating about MQA. This paper seeks to overcome this barrier by presenting a set of essential terms used in the business of MQA. It is the expectation that an understanding of MQA terms will enable states to better evaluate their own programs and improve state-to-state communication about MQA program development and the effectiveness of maintenance strategies.

MQA TERMINOLOGY

State agencies use a clear set of terms in the practice of MQA. These terms are used to describe the practice of MQA, and to facilitate the decision making. However, these terms vary widely from state to state, and are often used inconsistently between agencies. Furthermore, state MQA reports often do not define the terms that are used. This is obvious and readily apparent by reviewing agency documents on MQA programs. It was found that the same term is often used to describe subtle but importantly different concepts, and that states often apply different standards, even where they include similar features. In current practice, many agencies have adopted their own set of poorly defined terms.

This lack of agreement on terminology makes it difficult for maintenance officials to communicate among themselves and with those outside the maintenance profession. Agreement on common standards and measures is essential for states to engage in dialogue and information exchange regarding the effectiveness of various maintenance activities. Some features and characteristics upon which such dialogue could be based include rutting of pavement and retro-reflectivity of striping and signs.

Some terms for MQA are defined in *NCHRP Report 422* (*1*). Some agencies have adopted these terms. The definitions provided in the NCHRP report provide an excellent basis for the development of terminology for describing the artifacts and concepts of MQA. The following is a proposed set of terms and definitions for MQA. The definitions are consistent with, yet refine and expand upon the definitions presented in the glossary of the NCHRP report on highway MQA (1). In addition, the list includes definitions for terms like threshold and target that were not included in the NCHRP glossary.

1. *Maintenance category.* A maintenance category is a logical grouping of maintenance features based on their location or function along a highway. Examples include pavement, shoulders, and traffic management. Categories are made up of features whose condition is measured with respect to a particular characteristic.
2. *Maintenance feature*. A maintenance feature is a physical asset or activity whose condition is measured in the field. There is one or more maintenance feature in each category. Collectively the maintenance features describe the maintenance quality of a category.
3. *Maintenance characteristic.* A maintenance characteristic is a specific quality–defect in a maintenance feature that is condition evaluated (example: signs can be evaluated with respect to retroreflectivity, appearance, sign height, and other deficiencies).
4. *Standard.* A standard is a criterion or tolerance level for establishing the boundary between acceptable and unacceptable condition or function.
5. *Measure.* A measure describes how to quantify the deficiency of a maintenance feature or characteristic. For example: linear feet, percentage area, or amount of deficiency.
6. *Threshold*. A threshold is a predetermined systemwide maintenance level for features and categories. A threshold can be thought of as a grading scale or LOS indicator for MQA. Thresholds indicate how much or what percentage of the system is with or without deficiency. Thresholds also relate measures to customer satisfaction.
7. *Target.* A target relates thresholds to the maintenance budget. The target represents the expected threshold level that is attainable.

Figure 1 illustrates the hierarchical relationship between category, feature, and characteristic. A category is a group of related features. One or more characteristic is then assigned to each feature. The distinction between feature and characteristic is important; a feature is a physical asset or activity, while a characteristic is the physical quality or defect of the asset. Measures for maintenance quality evaluate the physical quality of the asset. The description of the measure is often then used to highlight the particular characteristic of the feature that is being evaluated. The flexible pavement, rigid pavement, and shoulder features are exceptions to this line of thinking. For these features agencies explicitly identify a set of characteristics and the corresponding measure for each.

The availability of a maintenance database has an impact upon how condition data is collected. Agencies tend to take advantage of existing inventory and condition assessment databases for MQA. When these databases exist agencies tend to use the available condition

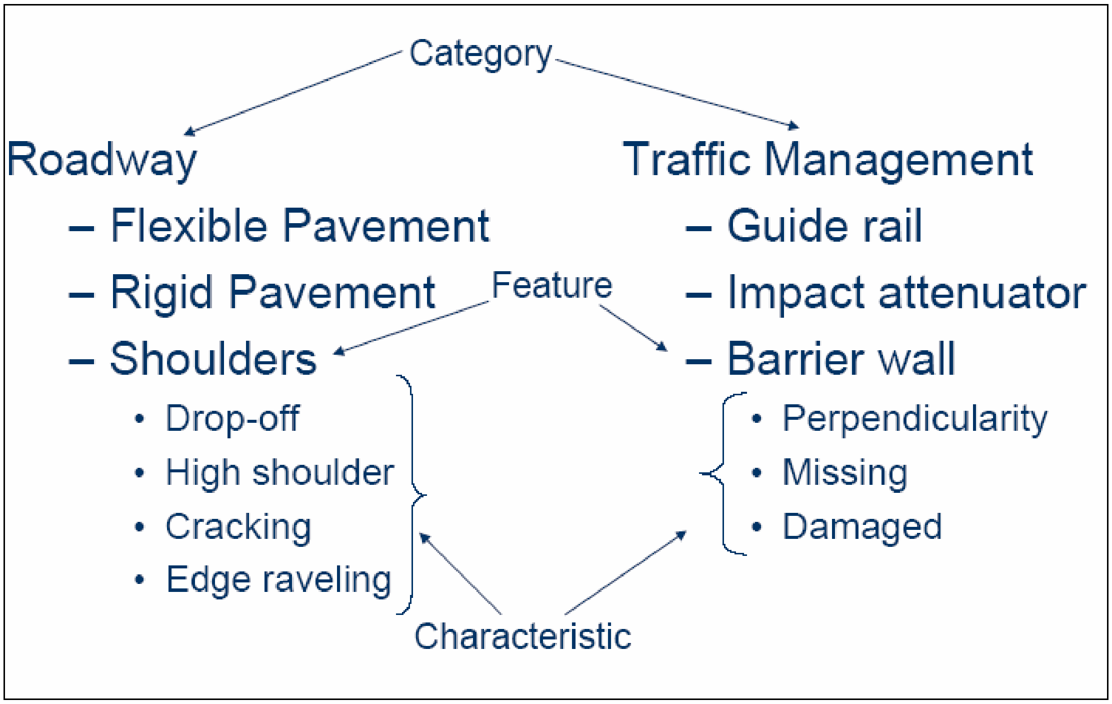

FIGURE 1 Relationship between category, feature, and characteristic.

information to assess the maintenance quality of a feature. Rigid and flexible pavements are examples of features for which condition databases exist. For most other features inventory and condition data is not readily available. It is thus necessary to collect data in order to assess maintenance quality. For these features agencies tend to use a random sampling strategy to collect data in the field.

MEASURES FOR MQA

The process for identifying measures involves several steps. First maintenance categories—logical groups of maintenance features based on their location or function along a highway—must be identified. The second step is to assemble an inventory of maintenance features—physical assets or activities whose condition is measured in the field, and maintenance characteristics—specific qualities–defects in a maintenance feature that are condition evaluated. In the third step, all categories, features, and characteristics with different names but similar functions are reconciled under one name. Finally, measures and standards are identified for each feature and characteristic.

Agencies tend to group features and characteristics into maintenance categories related to budgets. This practice enables maintenance officials to evaluate trade-offs among maintenance activities and to justify maintenance budget needs. Seven categories were identified from the documents submitted.

1. Roadway: Contains characteristics that are defective on pavement surfaces, and adjoining shoulders.

2. Drainage: Contains features that help to remove water from highways.
3. Traffic management: Contains features specific to maintaining safety along the travel way.
4. Roadside and vegetation: Contains features that are located along the roadside and within the mowing limit of the roadway.
5. Snow and ice: Contains activities relevant to snow and ice removal along a highway.
6. Bridges: Contains features specific to maintaining the quality of bridge structures.
7. Rest areas: Contains features located within a rest area and adjoining property (e.g., parking lot and picnic areas.

Many states use similar maintenance budgeting categories. As a result, there is good consistency amongst agencies regarding the maintenance categories that should be included in an MQA program. By contrast, there is little consistency amongst states regarding the features and characteristics that should be included and measured in each category. As a result, when applied the process for identifying measures revealed a large spectrum of features, characteristics, and associated measures. In fact the categories represented in this effort included anywhere from 5 to 20 features and characteristics.

Results also revealed that some categories are more developed than others. This fact is evidenced by the number of features or characteristics included in an MQA program, and by the number of features or characteristics with identifiable measures. Table 1 shows the largest, smallest, and average number of features or characteristics measured in each maintenance category. For example, a minimum of 1, maximum of 7, and average of 3.9 drainage features are measured in the MQA programs reviewed. The last column in Table 1 identifies the state MQA programs that measure the largest and second largest number of features–characteristics in a given category.

It is important to note that Table 1 only accounts for the features and characteristics for which measures could be identified. Similarly, the measures presented in Tables 2 through 10 account for the features and characteristics for which measures could be identified. MQA documents submitted also include features and characteristics for which no clear measures could be identified; these features–characteristics have been excluded from the analysis.

The measures for characteristics of the roadway features—flexible pavement, rigid pavement, and shoulders are listed in Tables 2, 3, and 4. Agencies tend to define measures for characteristics (quality defects that are condition assessed) of roadway features. The roadway category is unique in this respect; for all other categories agencies tend to define measures for features. The most likely reason is that most, if not all states that assess maintenance quality of pavements use data from their pavement management programs. These pavement management programs include characteristics and measures that have been well developed.

In addition, the tables list the standards or tolerance levels used to identify whether a feature is functioning as intended. It was determined that states utilize different standards, even where they use similar features and characteristics. There is thus little or no consistency among the agencies on how the need for maintenance is determined. This fact makes it very challenging to compare MQA practices based on the application of standards.

TABLE 1 Summary of Inventory Results

Category	Features–Characteristics Min.	Features–Characteristics Max.	Features–Characteristics Average	States Measuring Most Features–Characteristics
Roadway				
• Flexible pavement	4	10	6.6	Iowa and Missouri
• Rigid pavement	2	7	4.5	Missouri and North Carolina
• Shoulders	1	8	4.3	Maryland and Missouri
Drainage	1	7	3.9	Tennessee and Kansas
Traffic management	1	10	7.55	Colorado, Washington, D.C., Mississippi, and Missouri
Roadside and vegetation	3	9	5.9	Tennessee, Texas, and Wisconsin
Snow and ice	1	2	1.2	Tennessee
Bridges	1	4	2.1	Washington, D.C., and Missouri
Rest areas	1	5	3	California, New York, and South Dakota

Tables 2 through 10 list multiple measures for most features and characteristics. Many states use different measures and some states use more than one measure to express the deficiency of a single feature or characteristic. From the tables, three dominant geometries of features are apparent and patterns in the way certain geometries are measured observed. The discussion that follows focuses mainly on features. However, characteristics may also exhibit these geometries.

The geometry of features as they relate to roadway segments may either be continuous (e.g., line striping), discontinuous linear (e.g., ditches or fences) or point (e.g., signs). A continuous linear feature–characteristic is one that has a linear geometry, appears in consistent locations, and is continuous within a highway segment; line striping is an example of a continuous linear feature. A discontinuous linear feature is one that has a linear geometry, but does not appear continuously within a highway segment. Instead these features appear at individual locations along a highway segment and are ordered in a linear pattern. Another example of a discontinuous linear feature is a guard rail or a concrete barrier. The final type of geometry identified is the point. These features are not uniformly distributed along a highway segment and demonstrate no pattern or density. An example of a point feature is a sign.

For many features states use different measures that are parametrically related. For example some states record the total length of a feature and the length that is defective; other states simply record the percent deficient. An agency using the length that is defective or the percent that is deficient could produce the same measure depending upon the context of measurement. The deficiency of a uniform linear feature is often expressed as per mile or as a percentage of segment sampled; the deficiency of a discontinuous linear feature is often expressed in terms of the length or linear feet of damage; and the deficiency of a point feature is often expressed in terms of the total number deficient. If a feature is not of uniform size or distribution recording the percent of the feature deficient without indicating the number or size of the features observed, may lead to results that do not provide information about the magnitude of the maintenance work load. Retaining walls are features where such difficulty may be faced.

TABLE 2 Measures for Flexible Roadway Pavement Maintenance Quality

Characteristic	Standards	Measures per Segment
Rutting	Ruts in excess of the allowed depth require attention	• Depth of ruts • Number of ruts • Average rut depth
Potholes	Potholes in excess of the allowed depth or area require attention	• Area of potholes • Number of potholes
Cracking	Cracks in excess of the allowed width, depth, or length require attention	• Length of cracks • Number of unsealed cracks • Area of cracking • Percent of cracking
Raveling/ surface stripping	Any cumulative raveling greater the allowed length or area requires attention	• Percent of surface with raveling • Area of raveling
Bleeding–flushing	Bleeding–flushing in excess of allowed area requires attention	• Area of bleeding–flushing
Alligator cracking	Cracks in excess of the allowed length, depth or area in square feet require attention	• Area of cracking • Width of cracking • Percent surface with cracking
Depressions–bumps	All areas of depressions–bumps in excess of the allowed size in square feet require attention	• Height of depressions–bumps • Width of depressions–bumps • Area of depressions–bumps
Shoving	All shoving greater than the allowed depth requires attention	• Depth of shoving • Area of shoving
Edge break-up–edge raveling	Edge break up in excess of the allowed depth requires attention	• Depth of break-up • Length of break
Transverse cracks	Cracks in excess of the allowed length dept or area require attention	• Length of cracking • Width of cracking • Separation of blocks with cracking • Percent of pavement with transverse cracking • Number of unsealed cracks • Number of slabs with cracking
Patching	All patches larger than the allowed area in square feet must be repaired	• Area needing repair • Number of patches per lane
Ride ability–ride quality (composite)	• Any travel way where it is difficult to maintain speeds requires attention • Surfaces where cracks cause unevenness require repair • Surfaces that are cracked, worn or torn away require attention	• International roughness index (IRI)
Longitudinal cracks	Cracks in excess of the allowed length, depth or area require attention	• Length of cracking • Width of cracking • Percent of pavement with cracking • Number of slabs with cracking
Surface oxidation	• Surfaces where texture is worn by more than the allowed require repair • Surfaces with extensive large popouts require attention	• Percent of pavement surface with unwanted deficiencies or oxidized surface

TABLE 3 Measures for Rigid Roadway Pavement Maintenance Quality

Characteristic	Standards	Measures per Segment
Joints (seal)	• All unsealed joints require attention • Joints require attention if unable to keep out water	• Percent of joints not functioning as intended • Length of unsealed joints
Spalls–popouts	Spalls/Popouts greater than a specified area in square feet or depth require attention	• Area of spalling • Depth of spalls • Number of slabs with spalls
Cracking	Cracks in excess of the allowed length, depth or area require attention	• Length of cracks • Number of unsealed cracks • Area of cracking • Percent of pavement with cracking
Potholes	Potholes in excess of the allowed depth or area in square feet require attention	• Area of potholes • Number of potholes
Faulting	Faults greater than the allowed depth require attention	• Width of faulting • Average area of faulting
Depressions–bumps	All areas of depressions/bumps in excess of the allowed size in square feet require attention	• Height of depressions–bumps • Width of depressions–bumps • Area of depressions–bumps
Patching	All patches larger than the allowed must be repaired	• Area needing repair • Number of patches per lane
Transverse cracks	Cracks in excess of the allowed length, depth or area require attention	• Length of cracking • Width of cracking • Separation of blocks with cracks • Percent of pavement with cracking • Number of slabs with cracking
Rutting	Ruts in excess of the allowed depth require attention	• Depth of rut • Number of ruts • Average rut depth
Longitudinal cracks	Cracks in excess of the allowed length, depth or area require attention	• Length of cracking • Width of area of cracking • Percent of pavement with cracking • Number of slabs with cracking
Ride ability–ride quality (composite)	• Any travel way where it is difficult to maintain speeds requires attention • Surfaces where cracks cause unevenness require repair • Surfaces that are cracked, worn or torn away require attention	• IRI

TABLE 4 Measures for Roadway Shoulder Maintenance Quality

Characteristic	Standards	Measures per Segment
Shoulder drop-off to ground/ mainline drop-off/build-up	Shoulder drop-off requires attention when lower than travel way (e.g., 0.5 to 2 in. lower)	• Longitudinal length where drop-off is lower than warranted • Drop-off height where deficient • Number of occurrences of deficient drop-off • Percent of shoulder with deficient drop-off
Potholes	• All potholes greater than a specified depth (e.g., 0.5 to 4 in.) require attention • All potholes greater than a specified area require attention	• Depth of potholes • Area of potholes • Number of deficient potholes
Cracks	• Cracks greater that the allowed width (e.g., 0.25 to 1 in.) require attention • All unsealed cracks require attention	• Length of cracking
Pavement drop-off to shoulder/ pavement shoulder joint	• Pavement drop-off greater than the allowed length requires attention • Pavement drop-off requires attention when a certain percentage of the joint or drop-off has failed	• Longitudinal length of drop-off • Number of uncorrected defects • Height of pavement to shoulder drop-off
Surface–edge raveling	• Raveling requires attention when greater than allowed size in square feet (e.g., 1 to 2 in.) • Raveling requires attention when the width of deficient area is greater than allowed (e.g., 1 to 4 in.)	• Area of raveling • Percent of pavement surface with raveling
Non-positive drainage	Drainage requires attention when standing or ponding water evident	• Area of non-positive drainage
High shoulder/ distortion	Shoulder requires attention if height relative to travel-way is greater than allowed (e.g., 0.5 to 2 in.)	• Height of distorted/ high shoulder • Longitudinal length of distorted/high shoulder
Rutting	Ruts in excess of the allowed depth require attention	• Width of rutting • Length of rutting
Shoulder cross slope	• Cross slope requires attention if grade of cross slope does not meet requirements (usually expressed as a percentage) • Slope needs attention if flooding or ponding is observed • Slope requires attention if negative slope is observed	• Length of deficiency
Vegetation growth	None found	• Area of vegetated cover

The geometry of a feature (point, continuous linear, and discontinuous linear) tends to prescribe the dimensions of its measure, but there are exceptions. As was noted previously, there is very little consensus on the use of measures or on the type of measures to be used when quantifying the deficiency of a particular feature–characteristic. As a result there were several cases observed where the deficiency of a continuous linear feature was expressed in terms of the number deficient or length deficient. For many continuous linear features percent deficient is adequate because the quantity of the feature is implied by the segment length. For discontinuous linear and point features it may be best to record the quantity (area or length or number of) the feature along with the quantity that is defective. By recording both values, absolute (magnitude of the backlog) and relative measures are known. These values become particularly important if those interpreting measures wish to calculate average deficiency over a region. It is expected that in time, using the patterns highlighted herein, greater uniformity will be brought to the selection of measures to quantify maintenance deficiency.

Tables 5 to 10 list the measures for the drainage, traffic management, roadside and vegetation, snow and ice, bridges, and rest areas features. For these categories states assign measures to features; the characteristics are implied by the description of the measure. For example, in the traffic management category, signs are listed as a feature. The measures provided describe the ways in which post alignment, sign height, and sign reflectivity are quantified. Though not expressed explicitly these are the characteristics or quality defects that help to define the deficiency of a sign.

EVOLUTION OF MQA

To assess the evolution of MQA one could compare the state of the practice today to its condition at the time of Scottsdale. Today there are more categories used, MQA terminology has evolved considerably, and the measurement of customer satisfaction has evolved separately from the measurement of MQA.

The concept of organizing features and characteristics into categories for the purpose of MQA reporting has evolved to reflect spending categories and maintenance work activities. Categories identified at the Scottsdale event are still widely used (e.g., drainage, snow and ice, pavement surfaces, shoulders). Newly adopted categories include bridges, rest areas, roadside and vegetation, and traffic management. With the exception of potholes and rutting, the features, characteristics, and measures identified at the Scottsdale workshop were adopted unanimously by participants. Today rutting and potholes are the most widely measured pavement characteristics. It is interesting to note that the measures adopted at Scottsdale were adopted in theory. There is little evidence to suggest that states have put into practice all the measures adopted at Scottsdale.

MQA terminology has evolved considerably. For example, at Scottsdale, the participants of the workshop made little distinction between measures and features. In addition, terms like characteristic, standard, target, and threshold were not used in the proceedings of the Scottsdale event. These terms are now widely used throughout MQA literature.

The measurement of customer satisfaction has evolved independently of the measurement of maintenance quality assurance. Today agencies tend to consider customer satisfaction as related to but separate from their MQA programs. This is evidenced by the fact that documents submitted by agencies to the MQA library contain very little information on customer satisfaction

TABLE 5 Measures for Drainage Maintenance Quality

Feature	Standards	Measures per Segment
Ditches	• Ditches require attention when percent of ditch accumulation is greater than allowed • Ditches require attention when blocked by a certain amount • Ditches require attention when depth of standing water in pipe is greater than allowed	• Length or percent of ditch debris • Length or percent of blocked ditches • Percent of ditch debris accumulation • Length of ditch scour • Length or percent of ditch segment to be cleaned
Catch basin/ drop inlets	Inlet requires attention when full by more than the allowed amount (e.g., 25% to 50%) (expressed as a percentage of total inlet capacity)	• Number of inlets and catch basins • Number of deficient inlets and catch basins
Curb and gutter	• Curb and gutter requires attention if blocked by more than the allowed percentage (e.g., 25% to 75%) • Curb and gutter requires attention when functioning at less than the allowed percentage of design capacity (e.g., 50% to 90 %)	• Length of blocked curb and gutter
Culverts	Culverts require attention when blocked by more than the allowed percentage (e.g., 25%)	• Number of culverts • Number of obstructed or blocked culverts
Subsurface drainage	Subsurface drainage requires attention if functioning at less than a given percentage of design capacity (e.g., 90%)	• Length of subsurface drainage • Length of deficient subsurface drainage • Percent of inhibited flow area
Slopes/ slope failures/ washouts	Slope failure requires attention if a slide or erosion jeopardizes structural integrity; slide blocks shoulders or travel lanes	• Number of slope failures • Degree of slope (foreslope) measured to determine potential for damage
Drainage structures	Drainage structures require attention if the percentage of inhibited flow area is greater than allowed	• Number of drainage structures • Number of deficient drainage structures • Percent of inhibited flow area
Storm drains	• Drains require attention if a given percentage of cross-sectional area is restricted • Drains require attention if functioning at a less than optimal percentage of the design capacity	• Number of drains • Number of deficient drains
Pipes	Pipes require attention if blocked by a percentage that is not allowed (e.g., 25% to 50%), or if damaged or obstructed	• Number of pipes • Number of blocked, damaged or obstructed pipes

TABLE 6 Measures for Traffic Management Maintenance Quality

Feature	Standards	Measures per Segment
Non-regulatory signs and regulatory signs	Signs require attention if there is insufficient reflectivity, worn or missing characters in message, incorrect sign height, incorrect lateral clearance, or a deviation of post alignment from vertical is evident	• Number of signs • Number of signs deficient • Number of signs with poor reflectivity • Number of missing, damaged, illegible signs • Number of signs with incorrect sign height • Number of non-perpendicular signs • Number of signs with worn or missing characters • Number of signs with incorrect lateral clearance
Guide rail/ guard rail	Count as deficient any guard rail that is functionally or structurally impaired	• The longitudinal length of any guard rail that is not functioning as designed or has been damaged • Percent damaged as a function of original design capacity
Pavement markings	• Markings require attention if extent to which worn is greater than desired • Marking requires attention if distance of line from original location is greater than desired	• Number of markings • Number of deficient markings • Amount (length) of line damage • Distance of pavement markings from original location • Retroreflectivity of markings
Line striping	• Requires attention when percentage of paint missing from line exceeds allowed amount • Line requires attention if line is not visible from the required distance • Line requires attention if distance of line from original location is greater than desired	• Length of lines in segment • Length of worn, missing or damaged striping • Distance of line striping from original location • Retroreflectivity of line striping
Impact attenuators	Attenuators require attention if functioning at less than allowed percentage of design capacity	• Number of attenuators needing repairs • Length of deficient attenuators • Percent of attenuators free of defects

(continued)

TABLE 6 (*continued*) **Measures for Traffic Management Maintenance Quality**

Feature	Standards	Measures per Segment
Delineators	• Delineators require attention if a given percentage of reflectivity is missing, or worn • Delineator requires attention if vertical height alignment or perpendicularity varies by more than allowed amount	• Number of delineators that should be present • Number of delineators missing or defective
Barrier wall/ concrete barrier	Walls require attention once deficient or not functioning as originally intended	• Number of crash barriers • Number of crash barriers deficient or malfunctioning barriers
Raised pavement markings (RPM)	RPMs require attention if a given percent of original installation is deficient or not functioning as intended	• Number of RPMs that should be present in the segment • Number of deficient RPMs
Highway lighting	• Lighting requires attention if a given percentage of installation is not functioning • Lighting requires attention if the structural integrity of the lighting is compromised	• Number of highway lights • Number of highway lights deficient • Percentage of lights along segment that are functional/not functional
Guard cable	• Cable requires attention if damaged to the point of functional deficiency • Cable requires attention if there is deviation of horizontal alignment from design height	• Length of cable • Length of deficient cable • Number of cables not functioning as intended
Object markers	Markers require attention if consecutively non-functional markers observed	• Number of consecutive non-functional markers
Traffic signals	Signals require attention if not working properly	• Number of signals with lamp outages, improper signal operation or damage • Percent of traffic lights with bulbs not working, structural damage or non functioning loops
Intelligent transportation systems (ITS)	ITS requires attention if the percentage of non-functioning systems is more than allowed	• Percent of ITS systems not working

TABLE 7 Measures for Roadside and Vegetation Maintenance Quality

Feature	Standards	Measures per Segment
Litter/debris (roadside)	• Litter needs removal if visible at posted speed • Litter larger than an identified dimension (e.g., fist size) requires removal • Litter visible as one walks along roadside requires removal	• Length of litter • Number of pieces of litter counted • Percent of site with litter
Fences	Fence requires attention if it fails to provide a positive barrier, missing or damaged	• Length of fence • Percentage of fence requiring repair • Length of deficient fence
Brush and tree control	• Brush requires attention if obstructing vision, obstructing sight distance, or obstructing clear zone • Brush requires attention if encroaching upon travel way or blocking signage	• Number of instances of trees in the clear zone • Number of vegetation obstructions per segment • Percent of travel way free of encroachment
Mowing	Grass requires mowing once a given percentage of grassy area exceeds the allowed height	• Percentage of vegetated area mowed to standard • Average grass height over a specific length • Length of grassy area that is above the allowed height
Slopes	• Slopes require attention if the width of erosion is greater than allowed • Slopes require attention if the depth of observed ruts or washouts is more than allowed	• Length of slopes • Length of deficient slopes
Noxious weeds	• Weeds require removal if visible clumps are present • Weeds require removal if the percentage of infestation is more than allowed	• Length of highway where noxious weeds are present • Percentage of noxious weeds present per segment • Area of roadside • Area of infestation
Landscaping	Landscaping requires attention once area is no longer maintained at its original condition	• Area of landscaping • Area of poor landscaping • Percentage of landscape that is poorly maintained

(continued)

TABLE 7 (*continued*) **Measures for Roadside and Vegetation Maintenance Quality**

Feature	Standards	Measures per Segment
Sidewalks/ curb	Sidewalk requires attention once the percentage of sidewalk under visible distress exceeds allowed amount	• Area of sidewalk • Area of sidewalk that needs repair • Length of sidewalk • Length of non-functioning sidewalks
Graffiti	Graffiti requires attention if visible at posted speed	• Area with graffiti • Percent of surface free of graffiti • Number of hours following notification of deficiency that graffiti is removed
Litter removal (vegetated areas)	• Litter requires removal when visible at posted speeds • Litter requires removal when present within mowing limit or located at an unacceptable distance from mowing limit	• Number of pieces of litter
Retaining walls	Wall requires attention when undermining of rip-rap slope, paved ditch slope, or pavement is evident	• Percent of weep holes with blocked drainage • Linear feet of wall • Linear feet of deficient wall
Turf condition	Turf requires attention if no longer maintained at its original condition	• Longitudinal length of with poor sod • Percentage of turf maintained at below healthy condition
Curb trees/ sidewalk edge	Sidewalk requires attention if there is an encroachment of grass or vegetation along sidewalk	• Length of sidewalk • Longitudinal length of deficient sidewalk
Hazardous debris/ roadkill	Carcasses on shoulder, visible from the roadway or in roadway require removal	• Percentage of carcass removed following notification • Time taken to remove carcass

TABLE 8 Measures for Snow and Ice Maintenance Quality

Feature	Standards	Measures per Segment
Hours to bare lane	None found	• Number of hours taken to achieve bare pavement
Plowing activity	No roadway ice or snow accumulations shall be present 12 h after the local state supervisor is notified	• Number of hours after storm that plowing is completed
Statewide salt usage	None found	• Number of hours after storm that salting is completed • Amount of salt required to achieve pre-storm conditions

TABLE 9 Measures for Bridge Maintenance Quality

Feature	Standards	Measures per Segment
Bridge Deck (composite)	• All deficiencies larger than the allowed depth or length require attention. (e.g., minimum size 6 in. x 6 in. x 1 in. depth or larger) • Deck requires cleaning if sand or debris is present. • Sand or debris requires removal if flow of water or drainage on bridge deck is adversely affected	• Percent of deck surface with deficiencies • Total square feet of deficient deck • Total square feet of sand or debris
Drain holes	• Blocked drain holes require attention • Drain holes functioning at less than a given percentage (e.g., < 90%) of design capacity require attention	None found
Joints	• Joints functioning at less than an allowable percentage (e.g., < 90%) of functional capacity require attention • Joints require attention once a given percentage (e.g., 95%) of joint is blocked by debris or dirt • Joints require attention if unable to inhibit the longitudinal movement of the superstructure	None found
Bridge railing	• All damaged rails require attention • Railing requires attention if a given percentage does not function as intended (e.g., < 90%) • Out of place rails require attention	None found
Bridge approach	Approach requires attention if elevation difference is greater than allowed (e.g., > 1.5 in.)	None found
Bridge structure	• All dents that impact structural integrity require attention • Erosion that would have an adverse effect on thru roadway or structure requires attention • Graffiti requires removal if more than the allowed percentage of structure is covered • Graffiti requires removal if present	• Percentage of structure covered with graffiti • Percentage of graffiti removed within the required time following report
Painting	Steel structures exceeding the "non-deteriorated" range by more than a given percentage of rust (e.g., 1%) require attention	None found

TABLE 10 Measures for Rest Area Maintenance Quality

Feature*	Measures per Segment
Parking area	Condition of parking area
Condition of buildings	Appearance of building exterior
Condition of grounds	Appearance of grounds (landscaping, litter, etc.)
Condition of restrooms	Functionality of plumbing and dryers in restrooms
Restroom interior	Cleanliness and appearance of building interior

* No standards were identified for the rest area category

Today measures are often linked to a grading scale (threshold level) that is designed to reflect customer satisfaction, and the professional judgment of maintenance managers and transportation policy managers. The threshold levels for each measure are used to relate customer satisfaction to the maintenance work being done. Ultimately these threshold values enable comparisons to be made between features and categories based on maintenance quality.

FINDINGS

Terminology for MQA business has evolved significantly. However, there are still many inconsistencies, and few standards exist for the use of terminology or the application of definitions. As shown in this analysis, MQA terms are related by a hierarchical system. In this thesis the most critical MQA terms have been defined and presented to the reader. However, the inconsistencies and lack of standardization that exists in MQA have been highlighted in Table 1 which presents the alternate terms used in the business of MQA.

The poor development of MQA terminology has made it very difficult for MQA officials to communicate. In the absence of properly understood and defined terms agencies will continue to face difficulty communicating. In addition, the development of MQA programs will be negatively impacted by this language barrier. It is expected that the terminology developed and steps outlined in this paper will assist in the development of future MQA programs.

It was found that overall states use very similar categories to organize maintenance features and characteristics. The reason for good agreement on maintenance categories (e.g. roadway, drainage, traffic management, and bridges) is that they are tied to maintenance budgeting and work activities. Several of these budgeting and work activities are federally mandated, thus resulting in greater consistency. There is little agreement among the states on what particular features or characteristics are important to measure in each category. The decision of which characteristic or feature should be measured is made at a state level; there is no federal mandate, and thus there is less consistency. If MQA were to become a federally mandated program such as bridge management or pavement there could be improved consistency from state-to-state.

It was found that several states included traffic management in their MQA program. Such a result is to be expected as states face the greatest liability and thus the greatest responsibility for matters related to public safety on national roads. Maintenance of features in the traffic management category, or the lack there of, has the most direct impact upon the possibility for traffic accident and thus public safety.

Surprisingly roadway flexible and rigid pavements were included by few states. This can be attributed to the existence of pavement management programs. Pavement management programs are federally mandated programs and often involve pavement maintenance. As a result, most states exclude pavement maintenance from MQA programs.

When compared to the results of the Scottsdale meeting in 2000, MQA programs have evolved considerably. MQA has become a recognized business function at state transportation agencies. In addition, the measurement of customer satisfaction and maintenance quality has evolved independently.

RECOMMENDATIONS

Several actions are required by the broader maintenance community to further the development of MQA programs. Foremost is the adoption of a consistent terminology to facilitate the development of MQA programs and concepts. It is believed that a common understanding of terms like thresholds and targets will be essential to the future development of this field. (Thresholds are the grading scale indicator of maintenance deficiency at the county, district- or system-wide level. Targets represent the allowable–acceptable backlog and the expected threshold level that is attainable given the available budget.)

Next, there must be agreement on common standards as a first step towards commonly used measures. States have different standards, even where they have similar features. Agreement on common standards and measures are both essential for states to engage in dialogue and information exchange regarding the effectiveness of various maintenance activities. There should also be an effort to expand upon the comprehensive list of measures, and to develop consensus on measures for less commonly used features and characteristics. It is also recommended that agreement be reached on measures for maintenance features and characteristics for which there appears to be consensus (e.g., rutting of pavement, retroreflectivity of striping, and retroreflectivity of signs).

Finally, discussions should be held to ascertain whether or not the maintenance community is interested in moving towards common measures, that is, a set of standardized measures, for use in all MQA programs. The obvious features and characteristics for dialogue on common measures include rutting of pavement and retro-reflectivity of striping and signs. If in the future, maintenance officials are unable to reach consensus on common measures for MQA it is recommended that steps be taken to clearly articulate the process for identifying and defining measured in each state.

Clearly articulated definitions would allow maintenance officials to make comparisons across programs. From an outside perspective the ability to make such comparisons appears to be useful. However, at some point in the future the maintenance community will need to determine whether creating a system for comparison is in fact the ultimate goal for the use of measures in MQA.

Finally the maintenance community may need to determine whether MQA should be a federally mandated program. A federal mandate would increase uniformity in how features are measured from state-to-state. Discussions will need to be had about whether or not this is the direction that MQA needs to take.

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REFERENCES

1. Stivers, M. L., K. L. Smith, T. E. Hoerner, and A. R. Romine. *NCHRP Report 422: Maintenance QA Program Implementation Manual*. TRB, National Research Council, Washington, D.C., 1999.
2. Transportation Equity Act for the 21st Century (TEA-21). FHWA, U. S. Department of Transportation, 1998.
3. Hyman, W. *NCHRP Report 511: Guide for Customer-Driven Benchmarking of Maintenance Activities*, Transportation Research Board of the National Academies, Washington, D.C., 2004.
4. Monroe, E., J. Bittner, and A. Lebwohl. Proceedings Document: Maintenance Quality Assurance Peer Exchange, Midwest Regional University Transportation Center, University of Wisconsin–Madison and Wisconsin Department of Transportation, 2005.

Four Leadership Principles to Help Transportation Professionals

DAVID RAY
Ohio Department of Transportation

"Four Leadership Principles to Help Transportation Professionals" provides officials with practical leadership examples and a model to use people skills for results.

The four leadership principles in this model are

- **Vision,**
- **Empowerment,**
- **Teamwork, and**
- **Customer focus.**

Using these four principles, managers lead staff toward a common vision for customer satisfaction. Transportation features illustrated in a road model tell this story. The organization's vision becomes a billboard, clearly in front of us to move toward. Leaders use the vision principle just like a billboard to make their visions stand out, tell a story, and communicate simply. Traveling down this road, transportation professionals provide their people a foundation of empowerment on which to ride. Examples of empowerment are discussed such as employee annual work plans and empowering the workforce with hiring their managers. Teamwork keeps travelers on this road. This guardrail is made up of total quality management to focus on meeting and exceeding the customers' expectations. Examples are given how effective teams use problem solving processes. The last guardrail to keep them on the road is customer focus. Customer focus sets direction for business decisions. Surveys identify priorities for improvement with a goal to improve organizational performance as measured on the district's balanced scorecard. A transportation professional leader does not drive their people down this road, but instead, gives people a means to succeed on their own. The people part of these leadership principles will get you there.

A LEADERSHIP MODEL

Many excellent papers have been written about state-of-the-art maintenance operations. This paper breaks from an operations standpoint and discusses leadership philosophies that have been proven to work. How do you lead people to maintain your highways? From a broader perspective, what constitutes successful leadership? To help highway and transportation officials, there are four leadership principles the Ohio Department of Transportation (ODOT) uses to lead its staff toward a common vision for satisfaction among its many customers. Hopefully these principles can be used in your agency to achieve your organization's vision.

A model for transportation professionals shown in Figure 1 illustrates the four principles on the road to leadership success. Imagine your employees driving down this road. As a leader, you would not necessarily drive for them; but instead, you want to give them the means to drive down the road on their own by empowering them.

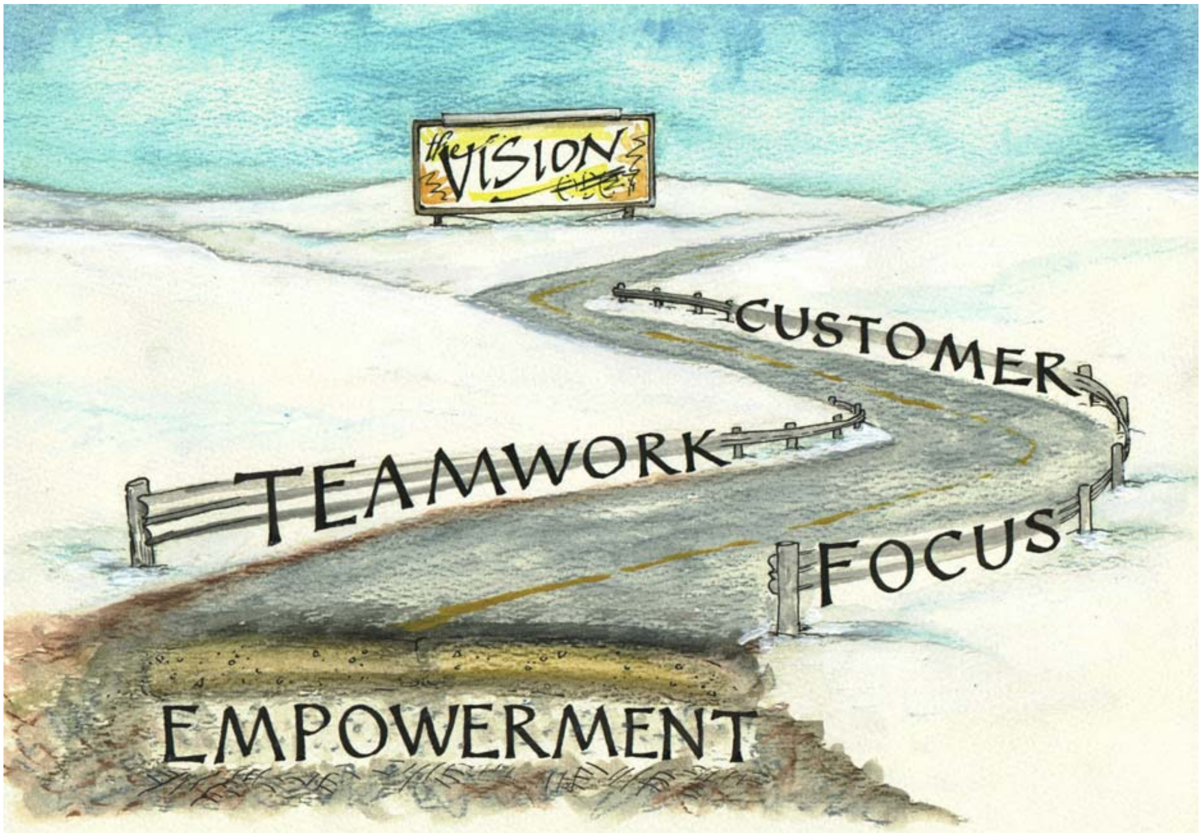

FIGURE 1 A road to leadership model. *(1)*

A leader also provides a clear vision or a billboard out in front for employees to see what is ahead. A leader keeps employees on the road with a guard rail called teamwork, and another boundary or guard rail called customer focus.

First and foremost how does this road to leadership model and examples help you? The goal to help you with the following.

- Successfully lead your staff toward a common vision for satisfaction among customers.
- Demonstrate how transportation professionals use four leadership principles showing best practice examples. Take these practical examples back to your workplace.
- Using a simple four-step model learn your responsibility for how leaders let their people "make it happen."

To accomplish these objectives "Four Leadership Principles to Help Transportation Professionals" will focus on people working to maintain our highways. This paper will take you down our road to leadership with vision, empowerment, teamwork, and customer focus.

VISION IS OUR BILLBOARD

At the ODOT District 12, the vision is bold for our maintenance employees. Our vision on the billboard for the road to leadership model comes in two statements and all the employees know them. First: "We will be second to none in snow and ice control." Second: "We will provide a safe, steady state system for our customers." Three S's to a good vision include:

1. Vision that **S**tands out;
2. Vision that tells a **S**tory; and
3. Vision that is **S**imple.

Our story was not always a great story to tell. In the words of then-director Jerry Wray, prior to 1995 ODOT had "fallen far short of even the most minimal standards of performance and excellence." ODOT's image was "of an uncaring, unresponsive and unmovable monster." Do you know of any organization described like this today? The leadership in 1995 decided it was time to re-engineer the organization and develop a sound vision based on trust with a common goal of good government for our customers. Focusing on that vision, District 12 has met 67 of the 71 district goals or 94% of the goals. In contrast, only 52% of the goals were being met just 3 years ago.

Leaders first must paint a clear picture of a vision that stands out to set the organization in motion toward it. Our "billboard" stands out in front of the road to leadership in clear view for the organization. Being second to none in snow and ice control and providing a safe, steady state system for our customers creates public value, not profit. Vision in public service needs to create public value for customers. With public value, your vision will stand out from the rest of the corporate clutter. For example, glimpse back in time to the American Civil War and look at leaders on both sides. One point stands out for Confederates and Union solders. Their generals and leaders mounted horses into battle. This fact made them constantly visible to their troops just like your vision needs to stand out and always be visible to your workforce.

It's hard work to be second to none in snow and ice control and maintain a safe, steady state. You instinctively know that a good vision will not be easy. When President Kennedy's vision said we would put a man on the moon in 7 years, it was not easy. When Bill Gates had the vision to put a computer on every desk in America, it was not easy and did not happen overnight. Those generals riding horses into battle also made themselves vulnerable targets to the enemy. As leaders, our vision imposes risks on us. That risk and the vision behind it must stand out. Just as we deliberately limit the number of traffic signs and advertising on our highways, do the same with your vision to make your "billboard" stand out. A vision that stands out is the first "S" of a good vision.

So that you can better understand our vision, this is what the people on the road to leadership do for our customers. Our district in Ohio encompasses three counties around greater Cleveland. To be second to none in snow and ice control poses special challenges when each winter we receive over 100 in. of lake effect snow as Figure 2 shows. Last year we averaged around 150 in. of snow and had locations that received over 200 in. of lake effect snow.

To make our winter vision a reality, 171 snowplow drivers log almost 1 million mi fighting storms with 85 trucks. Each winter they treat the roadways with more than 103,000 tons

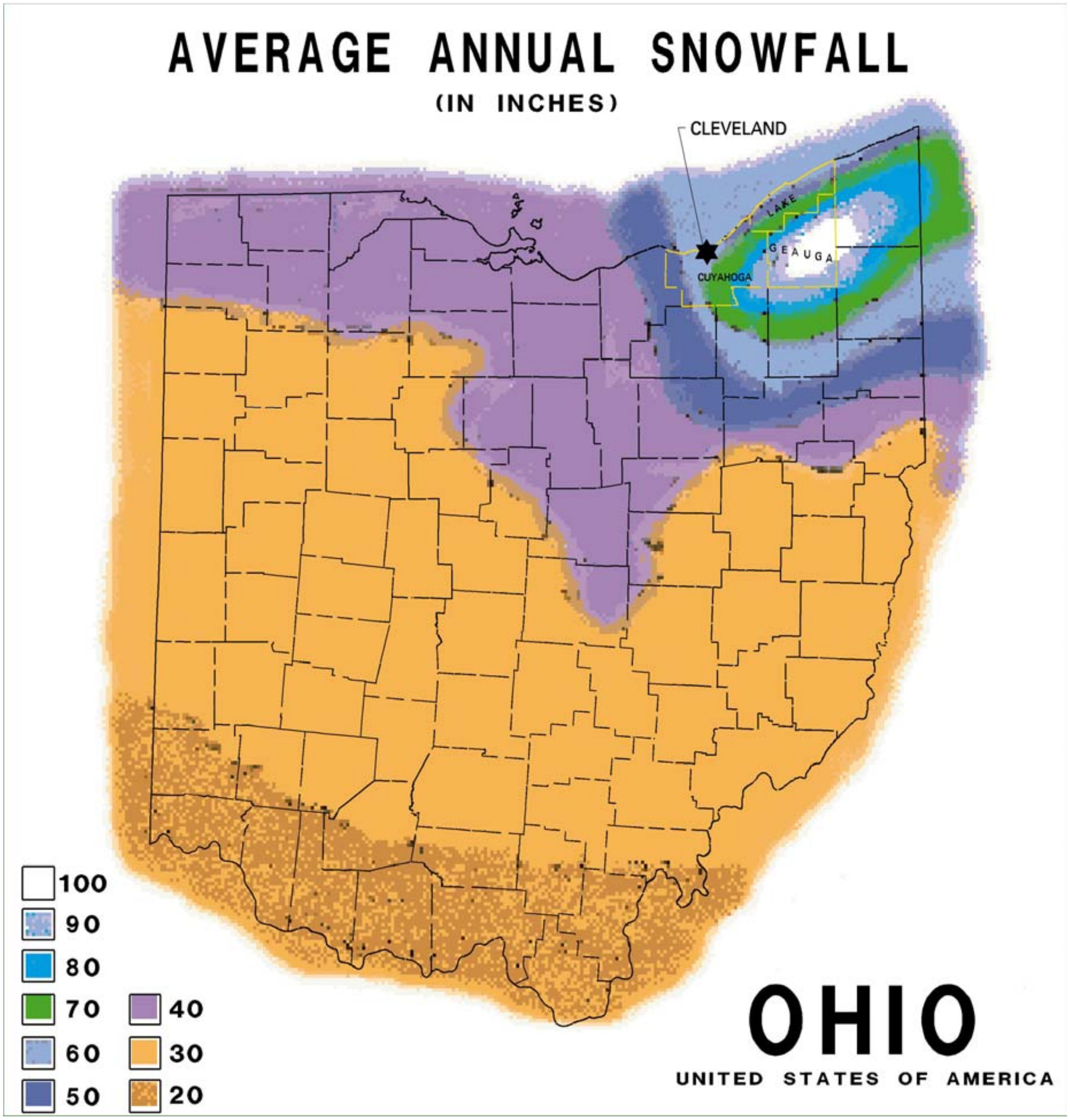

FIGURE 2 Ohio annual average snow fall (in inches) and Cleveland's District 12.

of road salt and 600,000 gallons of salt brine and liquid calcium chloride. For the other three seasons of the year, highway management teams build and maintain a safe steady state on 1,688 lane miles of highways and 526 ramps. Each of the three county's improvement efforts makes these miles of highways a safer, steadier state, which is our ultimate vision. We want our roadways to be as safe for the motoring public as possible. Our crews are making this vision a reality through their diligent pursuance of excellence. ODOT District 12 operates with 450 employees and 360 of them work directly in the front lines for highway management.

The second "S" to vision is that leaders use vision to tell a story. Walt Disney used a powerful vision to build theme parks for the whole family. The Walt Disney Company is a storytelling company. You can learn something about vision by looking at the story it tells. The Disney Company thrives on their ability to tell a story that connects to emotions. The understanding and appreciation for this power to tell an emotional story is a leader's key ability to set vision. Our vision to have safe highways is emotionally powerful. Safety motivates our employees to move with passion toward this common goal.

The third "S" to a good vision is that it must be simple. Is your vision simply understood? Being second to none in snow and ice control conveys a clear picture. The snowplow drivers understand it and even have this vision painted on their plows as Figure 3 shows.

The more simple and clear the vision is the better. For example, the Phoenix Arizona Fire Department's employees live and work by "prevent harm, survive, be nice." This is not long or strung out with fancy words (*2*). Make your vision simple. It's hard to get confused when our billboard reads a safe, steady state, and second to none in snow and ice control. Confusion can be eliminated if we remember what Colonel Hoot Gibson said "If you can't explain it to your mother, maybe you don't really understand it" (*3*). We understand that a safe, steady state means reducing deficiencies on our highways for our customers. It is simple and uncomplicated.

FIGURE 3 Highway technicians and mechanics with their vision: "Second to None."

Leaders promote simple visions on that billboard in front of their people that stand out, and tell a story. Using these three S's will make it easier for your people to reach your vision.

EMPOWERMENT IS OUR FOUNDATION

Traveling down the road to leadership proves impossible without the next step: empowerment. It is the foundation on which our people travel to reach the vision. My bricklaying instructor, Frank Rossi, always told us "Get the foundation right, with the first course of bricks being the most important, and the rest of your work will reflect your initial efforts." His wisdom proves true in all aspects of business whether bricks are involved or not. Empowerment is the first course of bricks and the foundation of a good leader.

For example, empowerment is used in employee annual work plans. Each year, workers come together and develop a plan they will utilize as a means to achieve their annual goals. Figure 4 shows the annual work plan process with empowered employees.

The annual work plan is based on the total number of hours the employees have to work in a year. The employees take these hours and subtract out the jobs they do best. These include how much time they estimate to plow roads for snow and ice control or other maintenance functions such as street sweeping or ditch cleaning.

FIGURE 4 Employee annual work plan process in District 12.

Our teams then balance these hours with hours they estimate to correct maintenance deficiencies. When all the work is identified, the hours of work for customer satisfaction exceed the number of hours per year. So the employees decide what work will be contracted out. The workers are the people closest to the customer and closest to the work, and they are the ones that have the answers. Managers then provide their employees with the material and equipment needed to complete the employee annual work plans.

The annual work plan process completely flip-flops top-down management into an employee first concept. Before annual work plans, ODOT operated on the long-standing tradition of doing things the way they have always been done. Work got done in the classic approach of top-down management. It even went as far as front line employees sitting around the garage in the mornings waiting for their managers to tell them what to do that day. Managers might go so far as to tell the workers what equipment they would operate and what section of road they would work on. With the annual work plan process crews are self directed and the top-down approach eliminated.

With the annual work plan, employees decide what work they will do to meet the goals and serve their customers. Ron Wiech is a front line highway worker and vice president of AFSCME (American Federation of State County and Municipal Employees) District 7 Lake–Geauga Chapter 4300. He sums the process up nicely: "The major factor in how we do our day-to-day work is trust. This happens because the work goes smooth with an annual work plan and self-direction. Managers can't be on the road all the time and we are out there." The employees become true self-directed work teams because they have already planned the majority of their work in their annual work plan. Self-directed work teams know the problems on their systems and they have a stake in the outcome as active members. Our workers get to finish the jobs they planned. These teams decide how the problem will be solved. Employee buy-in is solved. Management then supports the workforce by giving them the tools they need to implement the solution.

Annual work plans, self-directed work teams, and empowerment are not management pie-in-the-sky theories. These processes work with real results for our customers. The annual work plan is built around measures. Our measures are built around our vision. So, we put together our vision to have a safe steady state with empowered self-directed work teams using their annual work plan to generate results for our customers. When we set out to create a steady state in road conditions, the initial surveys showed that we had over 11,000 maintenance deficiencies on our system. Maintenance deficiencies include unsafe guard rails, shoulder drop-offs, damaged signs, and worn pavement striping. We worked on 16 maintenance repair goals and at the end of our first 3-year goal period, we met all goals eliminating deficiencies to less than 3,000. The results are impressive when you consider the size of our maintenance inventory. For example, empowered crews worked to attain 99.86% safe and functioning guard rail for the district's 203 mi of guard rail. They did this by reducing damaged guard rail throughout the district from 614 recordable deficiencies to 100 on the Interstates over 3 years and likewise reduced repairable locations 83% on the two-lane general system. Self-directed work teams improved the district's pavement system to 99.994% of the pavements being pothole free. Using their annual work plan our employees improved shoulder drop-offs for a safer system showing 99.79% of all shoulders had no drop-offs after the 3-year goal period. Conditions continue to improve using empowerment. Even after raising the goal levels on our measurements, we exceed the new levels with the annual work plan process.

Another example of empowerment is the way we hire managers. District 12 managers empower the workforce with the responsibility of having a say in who will manage them. Managers are selected by interview panels of equal numbers of bargaining unit employees from the AFSCME union and managers. The interview panel takes this assignment seriously.

"These are the people who work with you in the trenches and now you get to see if they have the qualities needed to serve the customer," says Cortez Browner, a Geauga County account clerk who is on an interview panel. "Being a front-line worker sitting on the other side of the interview table with the potential manager, you get to see what is important to the candidate."

Interview panels narrow the choices down to two or three candidates. These short-listed candidates are acceptable as managers to the bargaining unit-comprised team. Top candidates are the best of the group, and the employee-comprised interview panels identify strengths of each potential manager. The final selection of the manager is made by district's executive leadership, using identified strengths. These empowered interview panels work together to make the right decisions. Since starting the process in 1996, we have had 166 interview panels.

We have taken the next step in this empowerment process for management selection. Selection of the last two maintenance managers was done by an interview panel completely comprised of bargaining unit employees. There was no management representation at these interviews. The union picked who would be on the interview panels, then made the questions, interviewed the management candidates, and gave executive leadership a prioritized list of who would be best to manage over them.

TEAMWORK KEEPS THEM ON THE ROAD

Teamwork on the road to the leadership model represents a guard rail that keeps employees on the road. It is a powerful tool that helps direct people toward the vision. Teams develop buy-in when they come up with the solution. Leaders get excited working with teams. Dr. Jack Weber explains: "The bottom line is that leadership shows up in the inspired action of others. We traditionally have assessed the leaders themselves. But maybe we should assess leadership by the degree to which people around leaders are inspired" (*4*). We use teams to inspire. Teams change the way we do business in District 12.

We use total quality management and cross-functional teams to focus on meeting and exceeding customers' expectations. Teams are given the authority to make changes and the placement of that authority where the work is being done has improved the organization. Teams change the way we do business by making team recommendations in front of a quality-steering committee comprised of managers and bargaining unit members. When this quality-steering committee approves the team's changes in the operation, these new rules become operating practices. Anyone can charter a team to improve a process. Since 2003 we have had 54 chartered teams to change the way we do business with missions as lofty as improving our measurements to as simple as improving the way we record vertical clearance under bridges. Two-thirds of these teams have implemented their recommendations. The other teams are either active or standing teams that continue to improve processes.

How teams formulate these changes is an inspiring process. One of the most effective means used by teams to work through the problem solving process is storyboarding. Storyboarding is a way to brainstorm your team's ideas and put them out in the open for everyone to build on the good ideas of others. As Figure 5 shows, storyboarding lets the team

FIGURE 5 Storyboarding on teams for process improvements.

visually lay out their plan to implement change. The process takes a complex problem and breaks it down to understandable parts and then lists potential solutions.

Storyboarding captures the ideas of the team. It organizes complex problems and lists possible solutions. Storyboarding was originally used by Walt Disney to keep track of thousands of drawings needed for animation of cartoon features. Disney could quickly see how the project was coming along. Storyboarding allowed team members to build on possible solutions and encouraged free expression of ideas (*5*). The process moves along very quickly. For example on the Light Up District 12 team, team members identified over 100 problems keeping street lights on and grouped these into seven problem categories in little more than 15 min. Possible solutions were organized in a similar fashion with rapid responses.

When storyboarding, the team quickly sees problems and potential solutions. Solutions are agreed to by consensus. "Storyboarding lets you express your ideas and thoughts with no pressure on you regarding what you say," says Luis Cardona, a Cleveland garage highway technician. Luis was on a team to solve the problem of going to needed training while employees must work winter nighttime shifts. He said "The process allows you to see where you are going and build from others' ideas so that the team is all in the same ball park."

Teams outperform individual efforts. Take for example the highway lighting team, Light Up District 12. The team had a vision for a safe, steady state system that had an outcome of streetlights being on for safety. They were committed to understanding and meeting the needs of their customers, who expect to see lights in working order. Confidence in the department is undermined when the public sees that the lighting system is not being maintained properly. After a first inspection, the team knew that on average the district showed less than 80% of the 12,000 street lights were functioning.

This cross-functional team developed an action plan that stressed preplanning, self-directed work teams, and interdepartmental communication. The team implemented a method of feedback and measurement for success. They set a goal in the first year to have 90% of the lights working each quarterly inspection. By following their action plan, the team met their goal and currently 96% of all district street lights are operational.

Another team operates to manage the tax dollars provided to them. At the beginning of each budget biennium, 30 managers from highway management come together and build a zero-based budget. No money is automatically allocated to the departments at the beginning of the biennium. All requests for expenditures and overtime must be justified in front of this budget team. Each department questions other departments and comes to consensus on all budget requests. The team develops their own set of rules and even uses Nerf balls to keep other team members in order. If another team member breaks team rules, everyone is permitted to fire Nerf balls at the offender. This makes for lively meetings, keeps order through the proceedings, and provides a light atmosphere during stressful but critical discussions. All budget requests must be linked to the department's vision, goals, and customer service.

Accountability is set up with a zero-based budget because funding is approved and measured through the achievement of the department's goals. This team, using zero-based budgeting, thinks in terms of outcomes rather than inputs to produce desired results for customers (*6*). When we first used zero-based budgeting and added all the requests tied to our vision, we saved $292,000. By linking all requests to the department's vision and goals, we assure our external customers that funds are not being spent on someone's special interest. This team builds its budget from the bottom up, and shares a part of a $40 million budget from the beginning to the final expenditure.

GUARD RAIL FOR GUIDANCE: CUSTOMER FOCUS

Leaders guide our people down a road to an organization's vision. To keep them on that road, we stress customer focus. At the ODOT's District 12, everyone uses customer focus to set direction for our business decisions. Our surveys identify priorities for improvement with a goal to improve organizational performance as measured on the district's balanced scorecard. The highway management department uses a customer-focused approach for improving winter operations and external customer perceptions of the department. As Sam Walton, founder of Wal Mart said: "There is only one boss, the customer. And he can fire everybody in the company, from the chairman on down, simply by spending his money someplace else" (*7*). To gauge what customers think of us, we use snow spotter surveys and external customer surveys.

The district responds to its customers by using weekly snow spotter surveys during the winter. In the three counties around greater metropolitan Cleveland, our customers are contacted weekly to rate our winter performance. District 12's snow spotter survey is used asking professional drivers one critical question, "How did we do overall?" Managers in charge of the plow routes telephone snow spotters and use this customer feedback in their winter decision-making process. The results from this question in each county are tabulated to get results on a scale from 1 to 10.

Each week we have the opportunity to interact with 7 to 10 of our snow spotter customers per county. Our snow spotters range from police officers to truck drivers or delivery workers out on the highways in all types of weather. Snow spotters are dedicated volunteers and provide us with valuable feedback. If they see problem areas, they report these to our managers. This gives us an opportunity to improve and the managers an opportunity to correct the operation.

One part of our balanced scorecard is knowing what the customer wants within snow spotter scores. In 1999, our average scores were around a seven. When we engaged the managers directly in charge and started making changes as shown in Figure 6, results improved. Never forget that your team is the reason you are successful as a manager. County maintenance teams use the results to make improvements. Customers now consistently rate us between a 9 and 10 for our winter plowing, brining, and salting services. We have steadily improved because we listen to our customers, the snow spotters, and make improvements.

Improvements to winter operations have included:

- Utilizing the latest in technology—road and weather information systems and truck-mounted pavement sensors;
- Proactive maintenance practices—staffing using four shifts in the winter and pre-treating using salt brine applications;
- Equipment improvements—on board salt wetting, various plow blade combinations, carbide impregnated rubber plow blades; and
- Localized modifications for enhancement—changes to truck routing, spare fleet availability for breakdowns, and invisible boundaries between counties.

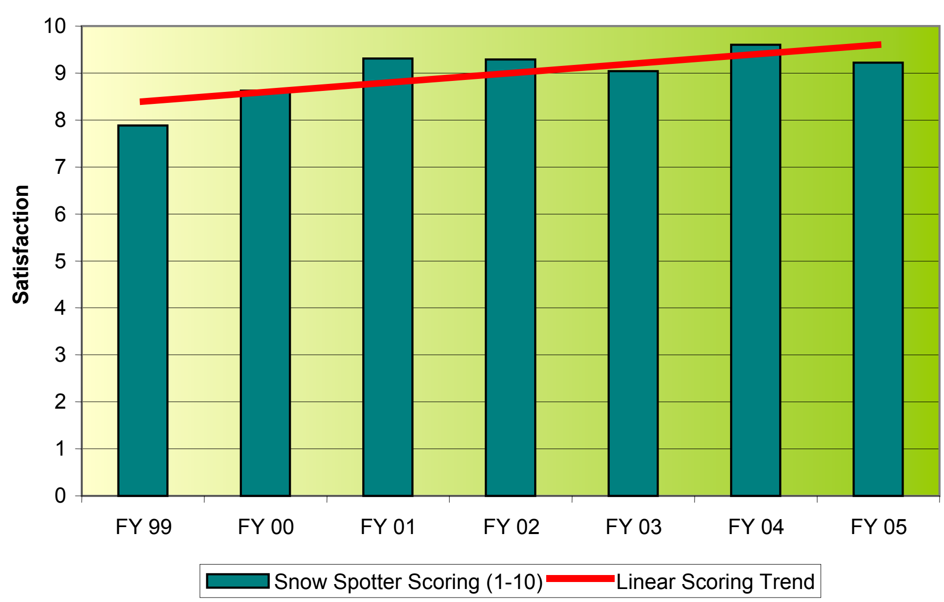

FIGURE 6 Snow spotter results—listening to winter customers.

All these are used to reach our goal of having pavements clear two hours after a storm. Weekly customer input helps get us to our vision of being second to none in snow and ice control.

Another gauge of customer satisfaction surveys external customers with more detailed questions. Measuring customer satisfaction helps prioritize work in the annual work plans and identify proper maintenance of traffic responses.

The external customer survey is a phone survey over our three counties. Respondents were called using a sufficiently large sample group (601 customers) to minimize sampling errors. The external customer survey is sponsored by the district's executive leadership team and implemented by the district quality services through partnership committee. The district quality service through partnership committee approves the survey instrument, analyzes the results, and creates an action plan, and reviews progress. Each surveyed driver is asked more than 80 questions.

In the past, public-service professionals protected the system and waited for politicians to change the organization. Now our organization survives because we have the vision to position ourselves for the future by listening to our customers. Positioning for the future must start with genuinely understanding your customers. Because we have listened and action planned for improvements the last 7 years our overall satisfaction has improved. Figure 7 shows overall satisfaction increasing 7% since 1998.

Contacts with the public are always important and the survey points us toward directions for improvement. The district quality services through partnership committee identify gaps between as is conditions and customer's expectations from the survey. This team identifies strategies to improve these expectations. For example, 38.3% of customers were not satisfied with the response or services received after contacting ODOT. The quality services through partnership committee recognized we needed to make changes in our customer inquire system. A

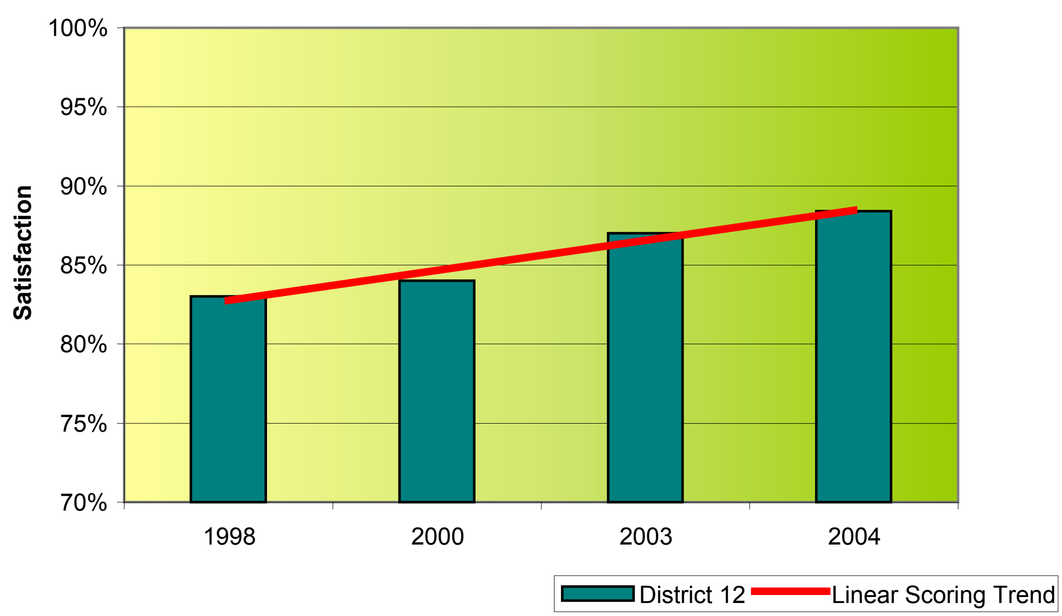

FIGURE 7 External customer satisfaction: improvements in overall satisfaction.

problem solving process team was charted and made recommendations to utilize a computer system (the customer information management system) to log incoming calls, assign a due date for those requiring follow up, and track the inquiry. Tracking is used so we can make data based decisions from calls received. Team rules include not transferring a customer more than twice and always having a live person on the phone to speak to between standard business hours.

Survey results for maintenance duties we perform showed that keeping roadways clear of snow and ice is the most important work we do. So the largest dollar amount expended in our annual work plans is snow and ice control. The importance that the public places on snow and ice duties is also apparent in past surveys. These surveys show the very high priority the public places on clearing the pavement in the winter of snow and ice. Judging from this and satisfaction results, we are the vendor of choice for winter service on Interstates and unincorporated state routes. So the next time you pick up that phone call about winter road conditions, remember they are calling you because you are the vendor of choice. It's our department that plows over 150 in. of snow per year and the customer calls us. The customer has decided who should plow these roads. Their action leads them to us. We are the vendor of choice and as transportation professionals we never want to lose this type of brand equity. Customer focus helps transportation professionals become a vendor of choice.

THE MISSING LINK TO THE FOUR LEADERSHIP PRINCIPLES

There is one big part of our road to leadership that is missing. The missing piece is the people that travel down the road with a leader's guidance. People are deliberately not shown on the model because any type of representation narrowly defines this broad category. The people are the part of the road to leadership that will get you there.

Former U.S. Secretary of State of State Colin Powell summed this up: "Plans don't accomplish work. Goal charts on walls don't accomplish work. Even talking papers don't accomplish work. It is people who get things done" (*3*). It is the snowplow driver in the winter on this road to leadership who decides every storm, what to plow, and how much to salt that makes the organization successful. That same driver might be the construction inspector in the summer that is working to minimize traffic delays on the project and improve customer satisfaction. Maybe in the spring this driver is the maintenance worker that is self directed to complete their annual work plan and make improvements for a safe, steady state. The people on this road are the most important part.

We don't define the one best way to be a leader. The people that work for you must find and follow their own path. We don't drive our employees down the road, or tell them how to get there. It is their performance that drives down this road, and as transportation professionals we use these four principles to guide them.

Leadership principles used by great leaders can be found and read about throughout history. Unfortunately, we tend to focus on the great leaders and forget about the followers. Focusing on the people that make our organization great is the underling point of this paper. Every day at work and at home, I'm reminded of the people part of a transportation professional's job. At my home, like in many other kitchens, our refrigerator serves as a place to collect family snapshots. Magnetic holders on our refrigerator show family members and the picture in Figure 8. It is a picture taken at our operational readiness inspection. Employees gathered at this inspection show they are prepared for the upcoming winter. Many times visitors to our home ask "Who are these people?" My standard answer is these are the men and women that keep my family safe every time we drive on our highways.

FIGURE 8 Cuyahoga county operational readiness team—people make it happen.

As transportation professionals, we use sophisticated equipment and state-of-the-art materials, yet nothing gets done without the people in our organizations. Professionally we have a responsibility to provide leadership. Vision, empowerment, teamwork, and customer focus are important principles in a leader's role. Guiding people using these principles is the essence of leadership.

REFERENCES

1. Artwork reproduced by permission from the artist, Meta Strick from Sheldon, Vermont.
2. Blanchard, K., and S. Gottry. *The On-Time, On-Target Manager: How a "Last-Minute Manager" Conquered Procrastination.* HarperCollins Publishers Inc., New York, 2004.
3. Harari, O. *The Leadership Secrets of Colin Powell.* McGraw Hill, New York, 2002.
4. Oakley, E., and D. Krug. *Enlightened Leadership: Getting to the Heart of Change.* Simon and Schuster, New York, 1991.
5. Capodagli, B., and L. Jackson. *The Disney Way: Harnessing the Management Secrets of Disney in Your Company.* McGraw-Hill, Boston, Mass., 1998.
6. Joyce, P. Using Performance Measures for Federal Budgeting: Proposals and Prospects. *The Journal of Public Budgeting and Finance Winter*, 1993, pp. 3–17.
7. *Jim's Favorite Famous Quote, Quip, Axiom, and Maxim Repository.* http://www.jimpoz.com/ quotes/speaker.asp?speaker=Sam+Walton. Accessed Nov. 1, 2003.

PART 6

Equipment

PART 6: EQUIPMENT

Using a Statewide Wireless Data Network for Maintenance Activities

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Automated vehicle location (AVL) technology is a well-known technology that first gained use in the trucking industry. It has moved into Indiana Department of Transportation (IDOT) operations primarily used in tracking winter operations. However, other maintenance uses are being tried.

Wireless data communications is needed with this technology. Commercially available systems primarily use cellular or short-range(10 to 20 mi) wireless data communications. The cellular option is costly due to the monthly service charges and is unreliable in some remote areas. The other option does not provide enough coverage range for some district operations.

So a research project was performed through the Joint Transportation Research Program at Purdue University to determine the viability and practicality of an AVL system that utilizes a statewide data communications system primarily used by the state police. The advantages of this approach are there no monthly data communication costs, the system is owned by IDOT, and it utilizes existing equipment.

This paper looks at a cost comparison with the other AVL options, explains the required hardware, describes the software and reports developed, and describes field test that were performed.

INTRODUCTION

Many factors influence the department of transportation's (DOT's) snow and ice removal efforts. Weather is the most important, but others include what chemicals to use, their application rates, what strategies to use, what equipment to use, and how to apply chemicals. Most of these are management decisions. Some of these decisions can be improved through the use of technology, and in particular the use of automated vehicle location (AVL) technology.

The current methodology of recording and entering winter operations information occurs "after the fact." The lack of current information can be detrimental. Also, documenting snow and ice removal equipment vehicle location and activities is crucial in determining what time to make another application and what and how much chemical to apply. Due to lack of timely information the DOT can be using vehicles improperly and wasting chemicals.

AVL provides the capability to electronically record the location and activities of winter maintenance vehicles. This data can be transferred electronically, thereby improving data accuracy, and feedback to managers that are responsible for making decisions on winter activities.

Organizations that have used this technology report quantifiable improvements in their winter activities. These include improved reporting data, better utilization of equipment, and savings in fuel and chemical costs. Also, with data electronically imported into a maintenance decision support system, management decisions can be made in a timelier manner.

This paper describes a system that was developed for the Indiana Department of Transportation (INDOT). This system utilizes a statewide wireless data network, commercially available hardware, and software developed for this application. The system described is non-proprietary and can be used by any DOT organization that has access to a wireless network.

POSSIBLE SYSTEMS

Two AVL options were considered and studied. Option 1 uses an AVL service provider where data is transferred via cellular service. There are numerous AVL service providers. Information was collected and a cost comparison was made. This cost comparison is shown below in Tables 1 through 3. This system consists of proprietary software and a monthly service of $40 to $60 per vehicle. Another commercially available system that utilizes short-range data communications was not considered due to lack of range(less than 20 mi).

Option 2 consists of using the Indiana SAFE-T wireless network to transfer data. The Indiana network is used by the state police and a coverage map is shown in Figure 1. Coverage is available in the northern two-thirds of the state. Installation is proceeding in the southern third of the state. Data is transferred through a 800-mhz radio network with a transmission rate of 19.2 Kb managed by Motorola.

INDOT has approximately 1,100 vehicles that participate in winter operations. Motorola did a data traffic study with this number of vehicles and determined that the data network has sufficient capacity to support this application along with the state police data traffic. All equipment and software would be owned by INDOT.

INDOT AVL SYSTEM

Since the cost differential between these options is significant Option 2 was chosen. Figure 2 is a conceptual diagram of Option 2.

VEHICLE HARDWARE

A detailed view of the in-vehicle hardware is shown in Figure 3.

1. Data collector. This can be either a rugged laptop, data terminal, or a vehicle PC with a small form screen. Touch-screen capability is preferred so the driver can select the road and weather condition values. The data collector will be used to collect data from the Global Positioning Satellite (GPS) receiver and the Muncie controller, capture driver input values, and

TABLE 1 AVL Options Cost Comparison (1,000 Trucks for 5 Years)

Options	Hardware	Parts	Model–Vendor	Cost per Part	*Subtotal*	Total Max. Cost
Option 1	In-vehicle equipment	GPS receiver + modem + data terminal	Multiple vendors	$500 to $900 per vehicle	$3,400 to $4,500 per vehicle	$4,500,000.00[1]
	Service fee		Multiple vendors	$2,700 to $3,600/ 5 years/vehicle ($45 to $60/ month/vehicle)		
Option 2	In-vehicle equipment	GPS receiver	GPS 18/Garmin	$130	$3355 per vehicle	$3,753,390.00[2]
		Radio modem + antenna	VRM 850/ Motorola	$1,900		
		Rugged laptop	ML 850/ Motorola	$1,200		
		IP setting software	MCSW2/ Motorola	$125		
	Base station		AVL server	$ 5,000	$398,390	
	Map-based control software		PU/INDOT	$ 0		
	File transfer module		PDMC application software/ Motorola	$393,390[3]		

[1] $4,500.00 x 1,000 trucks, assuming the service fee is not changing for 5 years
[2] $3,355.00 x 1,000 trucks + AVL server ($5,000) + PDMC Application Software ($393,390.00)
[3] See the following table for details
GPS = Global Positioning Satellite; PU = Purdue University; PMDC= Premier MDC

create a merged file and send it to the wireless modem to be transferred to the server (AVL server) on a set interval basis. The current interval is set at 3 min.

2. Muncie controller. This is a proprietary device sold by Muncie Power Products located in Muncie, Indiana. It controls the distribution of chemicals, salt, and liquids.

3. GPS receiver. This device receives the GPS signal and sends the coordinate values to the data collector.

4. Wireless modem. The data file is sent to the AVL server in Indianapolis through this device.

TABLE 2 Motorola PDMC Application Software (1,000 Trucks for 5 Years)

Year	Qty	Description	Cost	Subtotal	Total
Year 1	1	Wireless file transfer server module ($16,130)	$16,130		
	1,000	Wireless file transfer client module ($260)	$260,000		
		Maintenance	Warranty		
Motorola PMDC Application Software Subtotal (Year 1)				$276,130.00	
Year 2		Maintenance (10% of software cost)	$27,613		
Year 3		Maintenance (10% of software cost plus 4% escalation)	$28,718		
Year 4		Maintenance (10% of software cost plus 4% escalation)	$29,867		
Year 5		Maintenance (10% of software cost plus 4% escalation)	$31,062		
Motorola PMDC Software Maintenance Subtotal (Year 2–Year 5)				$117,260.00	
Motorola PMDC Application Software Total (5 years)					**$393,390.00**

TABLE 3 Cost Comparison After Year 5 Between Option 1 and Option 2

Year	Option 1		Option 2	
	Additional Cost	Total	Additional Cost	Total
Year 5		$4,500,000.00		$3,753,390.00
Year 6	+ $720,000[1]	$5,220,000.00	+ $32,304.00[2]	$3,785,694.00
Year 7	+ $720,000	$5,940,000.00	+ $33,596.00	$3,819,290.00
Year 8[3]	+ $720,000	$6,660,000.00	+ $34,914.00	$3,854,204.00

[1] Annual service fee = $720.00/vehicle/year x 1,000 trucks = $720,000.00 for Year 6.
[2] Annual software maintenance cost (10% of software cost plus 4% annual escalation) = $31,062.00 (Year 5) x 1.04 = $32,304.00 for Year 6.
[3] First year that Option 1 costs more than Option 3, assuming the service fee in Option 1 is not changing.

SOFTWARE

Two software programs are used.

1. Client software for data transfer. This software was developed by Motorola and has the trade name Premier MDC (PMDC). It controls and manages data transfer between the remote unit and the AVL server.
2. Purdue University (PU) data collection and merge program. This is a Visual Basic (VB) 6 program developed by PU that merges data coming from the GPS receiver, the Muncie controller, and from driver input. A data string is created and then transferred to the AVL server through PMDC. Data generated by the Muncie box is shown in Table 4.

FIGURE 1 Project Hoosier SAFE-T implementation map.

DATA MANAGEMENT

Each vehicle in the system will send a data file every 3 min to the AVL server. The files will be stored on the server in the directory (D:\avldata\Autoxfer\). Two reports will be generated from this data: (1) INDOT Chemical Distribution Analysis report and (2) the Indiana Road Condition Report. Both are map based. Figure 7 shows the data file organization, the processes that manipulate the data, and the report options.

This data is merged with the other fields and the merged file is shown in Table 5. Screen shots of this program are shown in Figures 4 through 6.

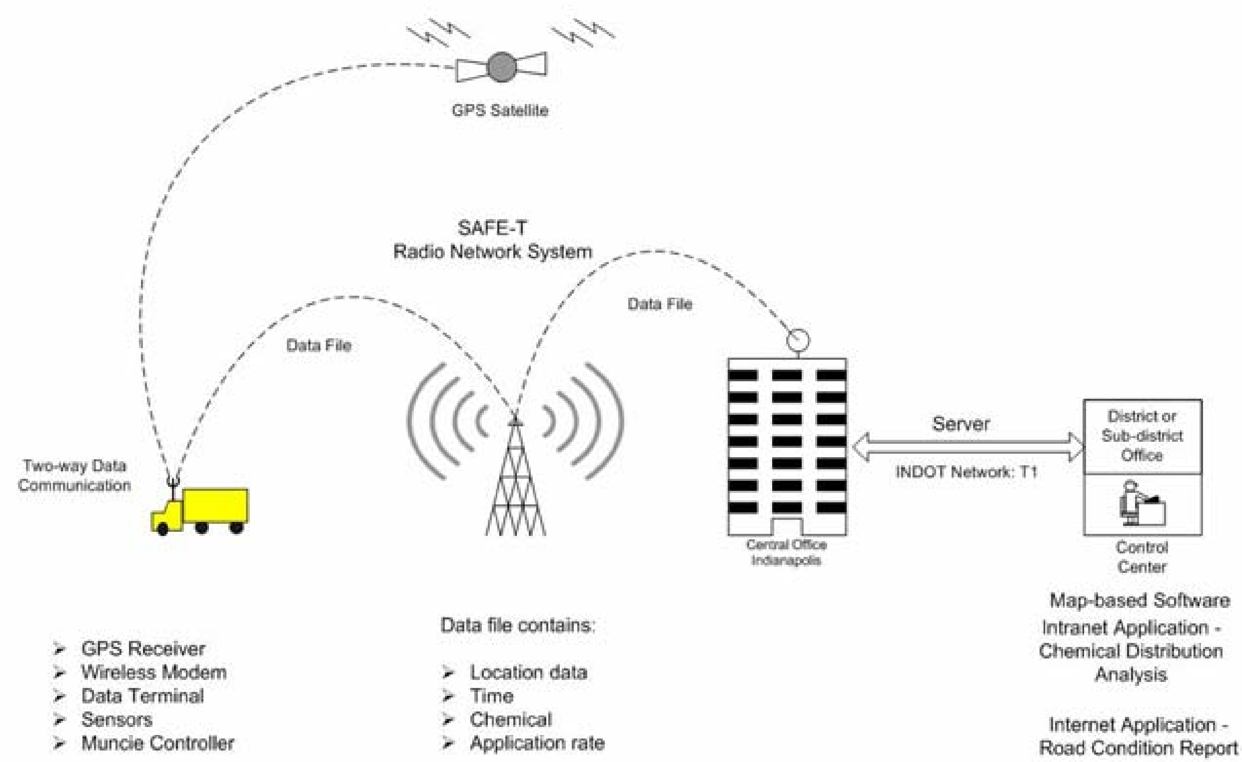


FIGURE 2 Conceptual diagram of INDOT AVL network using SAFE-T radio network.

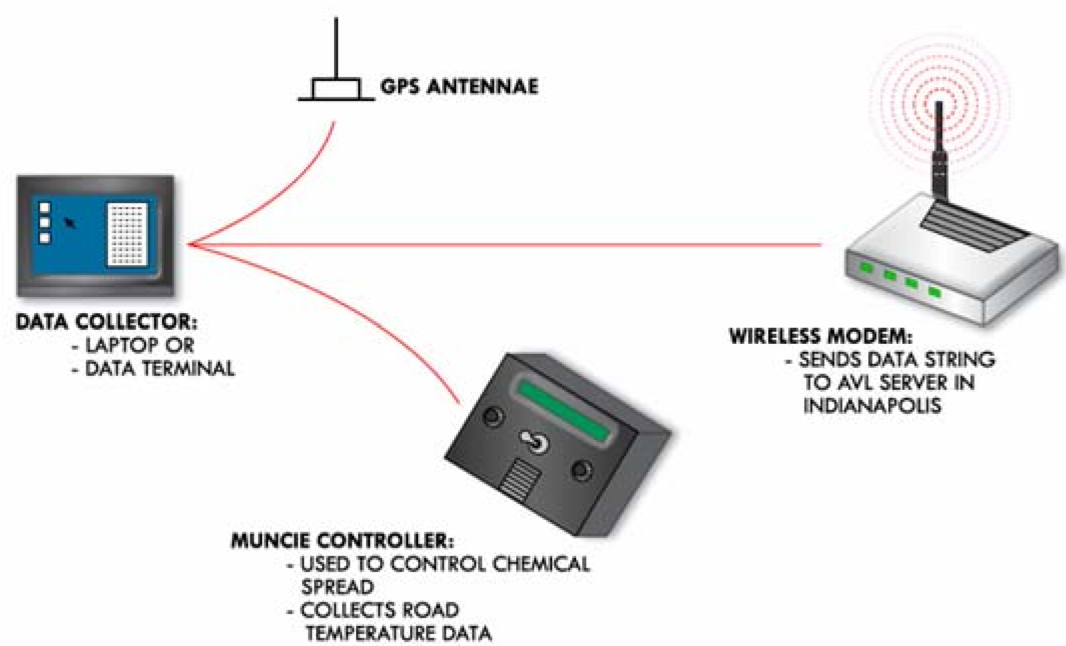


FIGURE 3 Vehicle hardware.

TABLE 4 Muncie Controller Data

Field	Definition	
1	*Mode*	N = Not Spreading; S = Spot; A = Auto; M = Manual
2	*MPH*	Current miles per hour
3	*Non blast lbs*	Total non blast pounds since reset
4	*blast feet*	Total blast feet since reset
5	*blast lbs*	Total blast pounds since reset
6	*liquid feet*	Total liquid feet since reset
7	*liquid gals x 10*	Total liquid gallons x 10 since reset
8	*miles x 20*	Total miles x 20 since reset
9	*road temp*	Road temperature
10	*air temp*	Air temperature
11	*product #*	Product No. 1 = sand; 2 = salt; 3 = alt 1; 4 = alt 2; 5 = alt 3; 6 = anti ice
12	*hh*	Hour of the time
13	*ss*	Second of the time
14	*dayofweek*	Day of week (Sunday as 1)
15	*year*	Year
16	*month*	Month
17	*day*	Day
18	*VID*	Vehicle identification

TABLE 5 Merged Data File

Column	Definitions	Column	Definitions
1	Time(hhmmss)	15	Road_temp
2	X(m in UTM)	16	Air_temp
3	Y(m in UTM)	17	Product_No
4	UTM_Zone	18	Hour hh
5	Distance(m)	19	Minute mm
6	Speed(mph)	20	Second ss
7	Mode	21	dayofweek
8	MPH	22	month
9	Non_blast(lbs)	23	day
10	blast(feet)	24	year
11	blast(lbs)	25	VID
12	liquid(feet)	26	Road Condition
13	liquid(galsx10)	27	Weather Condition
14	miles(x20)	28	volflow(lb/mile)

(a)

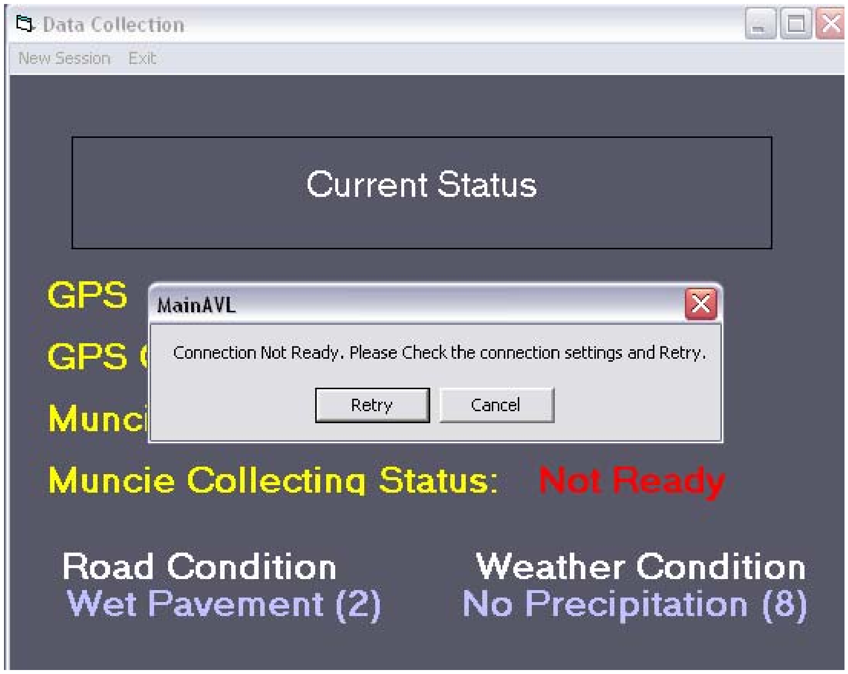
(b)

FIGURE 4 Road condition input screen: (*a*) first screen shows road condition, and (*b*) if nothing is selected, a pop-up will appear to prompt a driver to select a road condition.

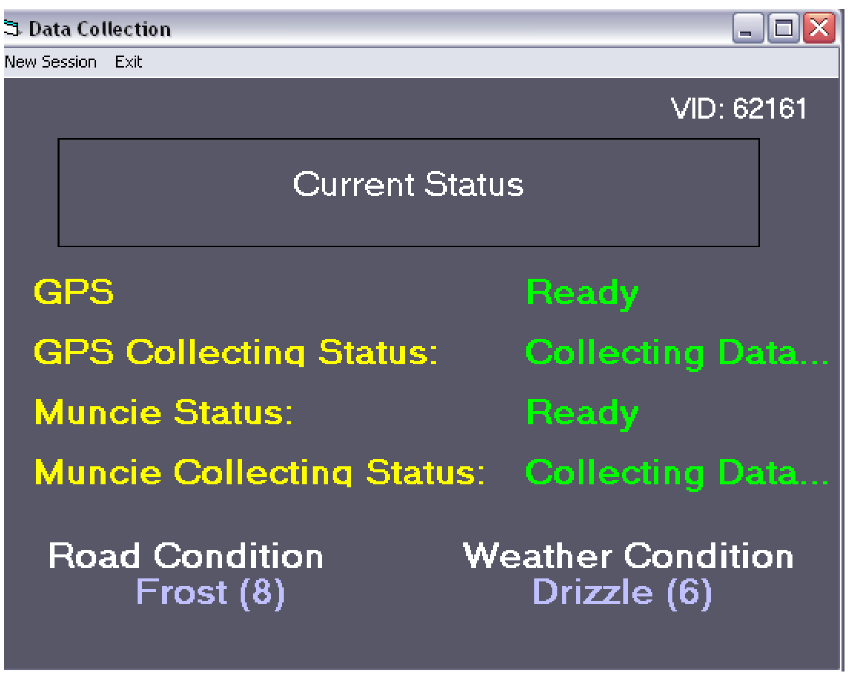
(a)

(b)

FIGURE 5 Weather condition input screen: (*a*) weather condition and (*b*) if nothing is selected, a pop-up will appear to prompt driver to select a weather condition value.



(a)



(b)

FIGURE 6 Driver information screen: (*a*) after both road and weather conditions are selected, the program will check for connections to both the GPS and Muncie devices. A pop-up will appear if the connections are not ready, and (*b*) if connections are ready, the vehicle identification will appear on the top right corner and the program will start collecting data and sending a merged file every 3 min to the AVL server over the SAFE-T network.

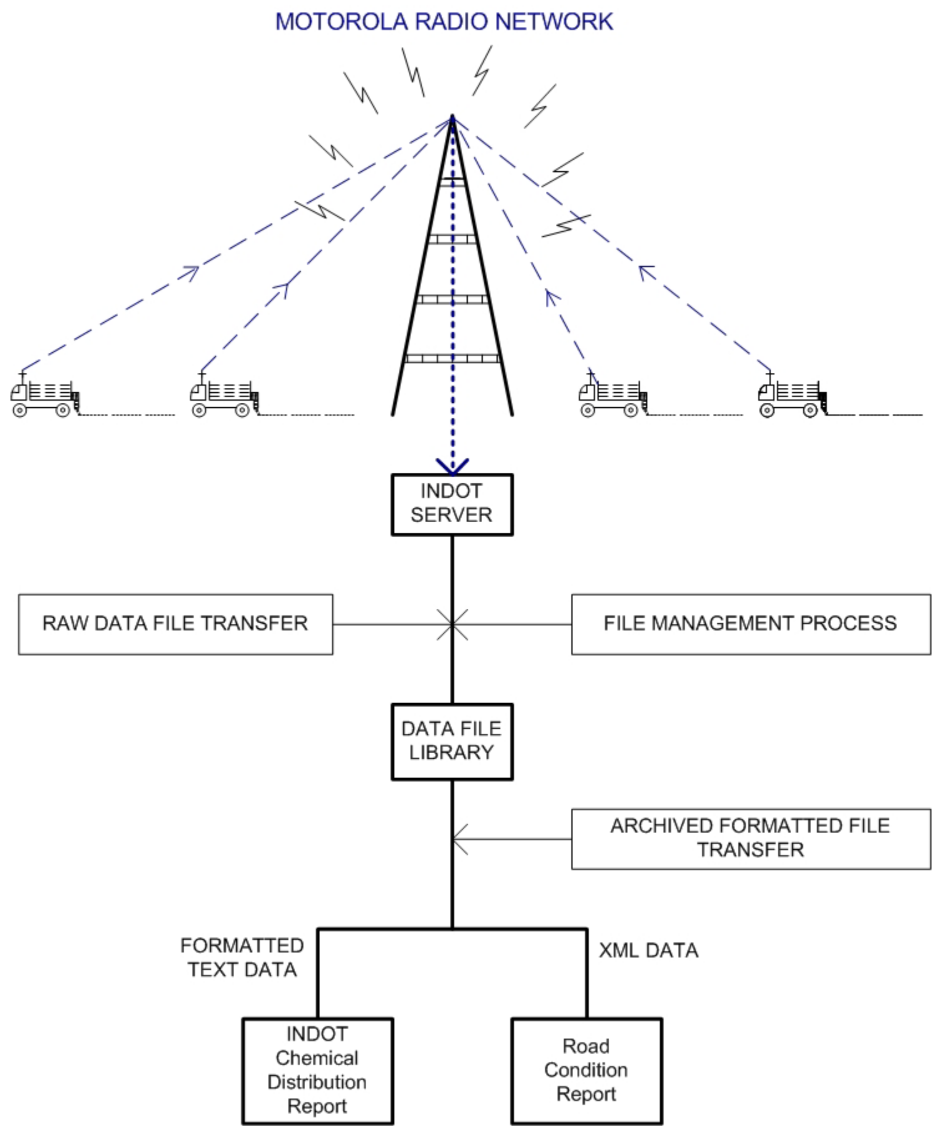


FIGURE 7 Data structure.

The File Management Process (FMP), is a server based process, takes the raw data files organizes and creates the map report files. The process works like this:

1. Every 3 min FMP merges raw data files obtained from different trucks and creates new xml and formatted text files. Both files accumulate data for a 4-h time period. The accumulating time periods uses military time 00, 04, 08, 12, 16, 20, and 24. FMP also removes received files in the (D:\avldata\Autoxfer\) every 3 min, making this folder serve as a buffer for receiving truck data files.

The Chemical Distribution report shows data for a 4-h time period. At the completion of a 4-h time period FMP creates an archived folder with a date and time name (e.g., 2005/12/25/16). The Indiana Road Condition Report displays current road conditions for a 4-h time period but its data is not archived. The reason for not archiving is travelers are only interested in current road conditions and not past road conditions.

2. The process starts over for the next 4-h period. The archived files can be retrieved and viewed by selecting a date and time period.

REPORTS

Two reports display the data. The formatted text file is used in the INDOT Chemical Distribution Analysis Report and the xml file in the Indiana Road Condition Report.

The Chemical Distribution Analysis Report is a VB application using map objects and can be used on any desktop connected to the INDOT private network, either in the INDOT central office, districts, or sub-districts. Data display includes truck identification, speed, application time, application rate, chemical type, road condition, weather condition, and road temperature. Figure 8 shows the report option for speed.

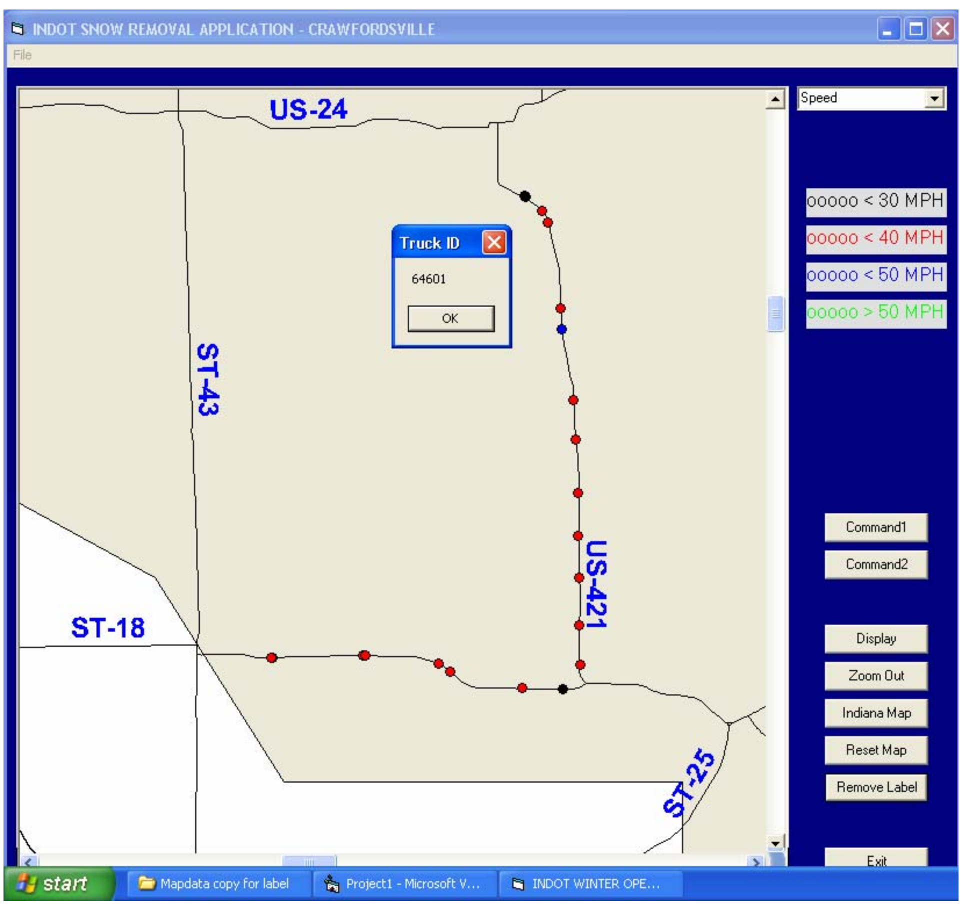


FIGURE 8 Vehicle speed option.

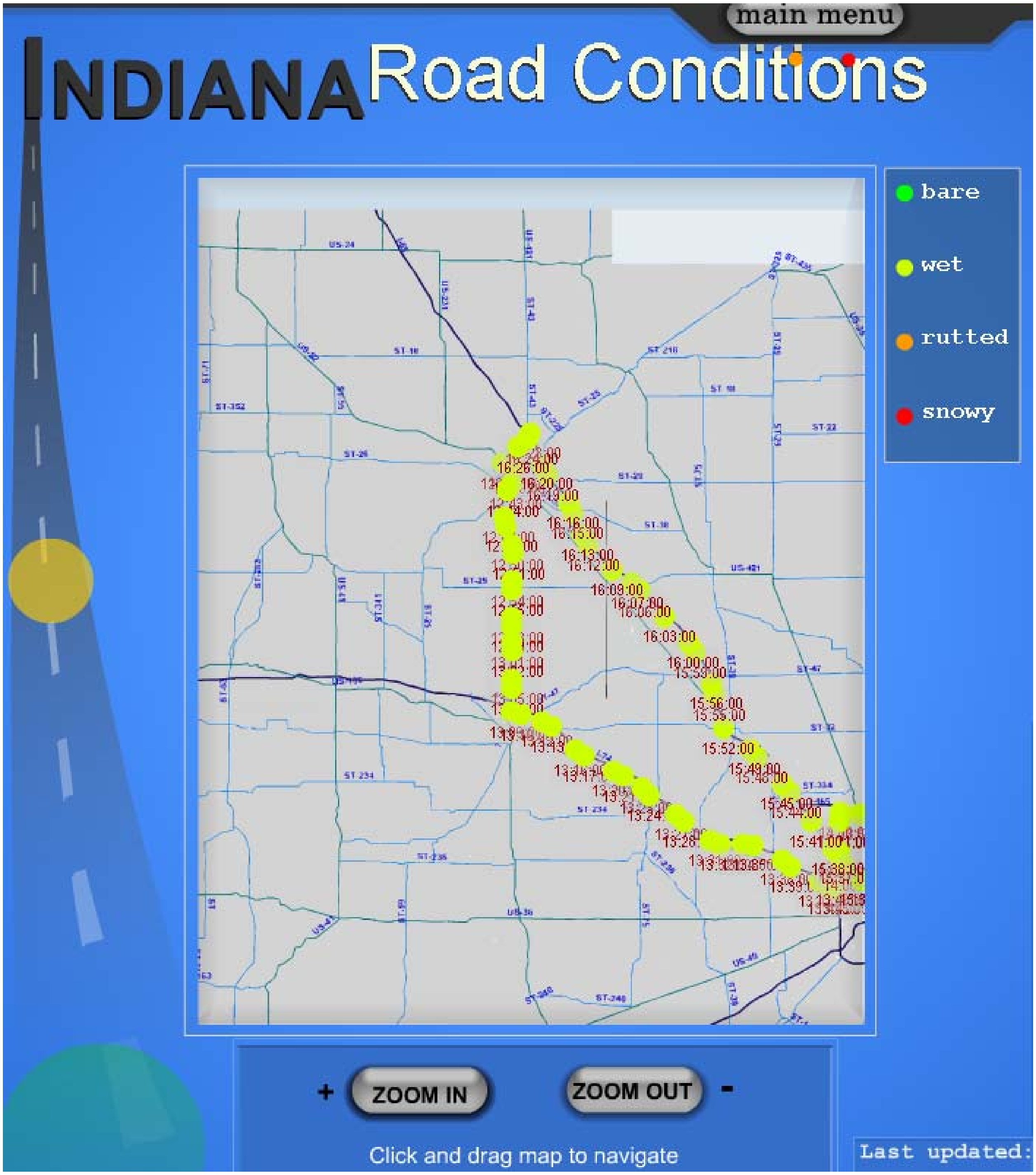


FIGURE 9 Road condition report.

The Indiana Road Condition Report uses xml data and a Flash application to display road conditions for the same 4-h time periods described previously. This is an internet application that runs on a browser (Internet Explorer preferred) and requires the Flash player which is a free down load from Macromedia. Since the data is in xml structure it can be transferred into other management tools like CARS. Figure 9 shows this report.

FIELD TESTS

In November 2005 at the Monticello and Columbus sub-district offices field tests were performed. These tests consisted of 1-day tests using the above described hardware and software and two snow plow vehicles. On these 2 days winter weather was not occurring so the spreaders simulated material distribution.

The field test results went well. The trucks were transmitting data every 3 min, the server received the files and the desktop report and web report were displaying the data properly.

Lessons learned from the tests were (1) driver interaction with the hardware and software has to be at a minimum and (2) reports were improved with the type of data reported, the range of values, the reporting intervals, and the map symbols used.

After these 1-day tests it was decided to fully equip two trucks at each location for the winter of 2005–2006. At the paper submission deadline this has not occurred. Equipment has been ordered and software and reports revised. At the meeting in July 2006, these winter results from using the four trucks will be reported.

ACKNOWLEDGMENT

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PART 6: EQUIPMENT

Equipment Quality Improvement Measures

Large Truck Fleet

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This paper discusses the findings of a Quality Improvement Team (QIT) established by the Utah Department of Transportation (UDOT) to evaluate the utilization and efficiency of the UDOT large truck fleet. The fleet is heavily utilized during winter months when snow removal operations require the use of all available resources. During summer months the demands on the fleet are not as great and some trucks are used very little or not at all. The QIT examined different alternatives to increase the utilization of large trucks during summer months while maintaining the level of service (LOS) provided for snow removal operations during the winter months. One important outcome of the study was the development of a snow removal model. The model provides instant feedback on the LOS that can be expected due to any changes made to snow removal resources. The QIT examined many alternatives and two offered promise to help achieve the goals of the QIT. The first alternative is to identify areas where efficiency can be improved, and reduce the overall size of the fleet. The second alternative is to create a partnership with other state government agencies to "share" equipment. The second alternative is promising as many other state agencies utilize equipment heavily in the summer and very little during the winter.

INTRODUCTION

The Utah Department of Transportation (UDOT) maintains a large fleet of 10-wheel, drop-axle, and bobtail trucks (large truck fleet) for its maintenance operations. The size of the fleet is approximately 487 vehicles. During winter months (October through March), the large truck fleet provides snow and ice removal services on all state roads. During this period the fleet is heavily utilized in order to provide "safe and passable" roadways during and after winter storm events.

UDOT also uses the large truck fleet for summer maintenance operations including: roadway patching, chip seal operations, material hauling, and other maintenance activities. The need for large trucks to perform these operations during summer months is not as great as the need for large trucks to perform winter operations. The result is that a portion of the large truck fleet is utilized very little, or not at all, during summer months.

UDOT formed a Quality Improvement Team (QIT) to find ways to address low utilization of the large truck fleet during the summer months. Members of the QIT included equipment managers, operations engineers, and maintenance personnel.

The QIT was originally asked to develop two plans for presentation to UDOT upper management. The first plan was to show how the size of the large truck fleet could be reduced by 10%. The second plan was to show how the size of the large truck fleet could be reduced by 20%. Both plans were to show how the utilization of the remaining fleet could be increased in order to maintain the same level of service (LOS) provided for winter and maintenance operations.

The size of the UDOT large truck fleet is determined by snow and ice removal operations. The QIT decided that a reduction in the size of the fleet could not occur without affecting snow and ice removal LOS. The QIT did agree, however, that a reduction in the size of the fleet would not affect summer maintenance operations to the same degree.

In order to maintain the winter operations LOS the QIT explored different alternatives that focused on maintaining the same LOS for winter operations. All of the alternatives were reviewed and analyzed by the QIT to determine which, if any, of the alternatives provided a feasible solution. Feasible alternatives had to meet certain criteria to be advanced for further study. The QIT established costs, effect on winter operations, effect on other maintenance operations, and liability risks as the most important criteria in evaluating alternatives.

BASELINE

A baseline or benchmark is necessary to compare alternatives. The QIT established benchmarks for the number and type of trucks in the UDOT large truck fleet, the cost to own and operate the trucks in the large truck fleet, existing snow removal operations, and liability.

Low Utilization During Summer Months

The QIT was formed to address the issue of low utilization of the large truck fleet during summer months. It is important to understand contributing factors that lead to low utilization of some trucks during summer months. Understanding these contributing factors is key to understanding how and if utilization may be improved.

It is important to note that UDOT must maintain a certain LOS on its roadways during winter storm events. Maintaining an acceptable LOS requires the maintenance of a large fleet of snow removal vehicles that are ready to go at any time during the winter season. Snow removal is the first priority of these vehicles. However, during summer months the vehicles are used for other maintenance activities. As the QIT went through the process of examining large truck operations, they viewed the fleet as a snow removal fleet first, and as a maintenance fleet second.

Major repairs are often performed during summer months leading to low utilization of some trucks. In addition to major repairs, other major maintenance is performed including painting, upgrades, and hydraulic overhauls. Major repairs and maintenance often take a considerable amount of time to complete. Because the first priority of the UDOT large truck fleet is snow removal, repairs and maintenance must be performed during summer months as often as possible.

UDOT procurement practices for large trucks also lead to low utilization of some trucks during summer months. Replacement trucks are ordered in July. When new trucks arrive they need to be modified and equipped with all of the specialized snow removal equipment required to conduct effective winter operations. This process can take as long as 1 year to complete. While the new truck is being equipped, maintenance personnel often let the old truck being replaced sit idle. This prevents unnecessary breakdowns and repairs on an older truck that is going to be turned in.

Another reason trucks are not used during summer months is a shortage of manpower. UDOT has instituted a transportation technician program that sends many maintenance personnel to construction crews during the summer months. This allows personnel to gain valuable experience in construction projects, but it limits the amount of work that is performed by maintenance crews during summer months. This in turn affects the usage of the large trucks. Personnel also use the majority of their vacation time during the summer months creating a shortage of manpower.

Large Truck Fleet

The UDOT large truck fleet is made up of bobtail trucks, 10-wheel trucks, and drop-axle trucks. Bobtail trucks are the smallest of these three types. Bobtails are single-axle trucks that may or may not be equipped with a dump bed. Most bobtails in the UDOT fleet are equipped with permanently attached 5.5 cubic yard sander.

Ten-wheel trucks are double-axle trucks and are equipped with a dump bed. A 10-wheel truck may be equipped with a 7.5 yd^3 sander, a 1,800-gal liquid tank, or a combination of both for snow removal activities. These trucks can also be equipped with wing plows and pre-wetting tanks.

Drop axle trucks are the largest trucks in the UDOT large truck fleet. Drop-axle trucks are triple-axle trucks and are equipped with a dump bed. A drop axle truck may be equipped with a 12 yd^3 sander, a 3,000-gal liquid tank, or a combination of both for snow removal activities. These trucks can also be equipped with wing plows and pre-wetting tanks.

UDOT has subdivided the state into four regions, with Region 4 being subdivided again into three districts. Each region and district is responsible for the maintenance and upkeep of its large trucks. Table 1 shows the trucks assigned to each region and district.

Costs

Cost savings is a critical element in evaluating the viability of any alternative to reduce the number of trucks in the large truck fleet. A base cost for operating the existing UDOT fleet was established to determine whether cost savings could be realized by implementing different alternatives.

TABLE 1 UDOT Large Truck Fleet as of April 2005

Region or District	Bobtail	10-Wheel	Drop-Axle	Totals
Region 1	8	90		**98**
Region 2	12	102	2	**116**
Region 3	4	83		**87**
Richfield	1	59	-	**60**
Price	4	60	1	**65**
Cedar City	8	53	-	**61**
Totals	**37**	**447**	**3**	**487**

TABLE 2 UDOT Large Truck Fleet Average Monthly Costs of Operation

	Bobtail	10-Wheel	Drop-Axle	Totals
Avg. Monthly Cost per Truck	$1,170	$1,210	$1,210	**N/A**
Region 1	9,360	108,900	0	**118,260**
Region 2	14,040	123,420	2,420	**139,880**
Region 3	4,680	100,430	0	**105,110**
Richfield	1,170	71,390	0	**72,560**
Price	4,680	72,600	1,210	**78,490**
Cedar City	9,360	64,130	0	**73,490**
Totals	**43,290**	**540,870**	**3,630**	**$587,790**

The UDOT equipment operations group establishes life-cycle costs for each of the different types of trucks in the UDOT large truck fleet. The life-cycle cost was broken down into a monthly rate to determine average monthly operating costs for the large truck fleet. Table 2 shows the baseline costs of operating the UDOT large truck fleet.

One positive outcome of creating the cost baseline was the realization that the costs to own and operate a 10-wheel truck versus a drop-axle truck are very similar. This allows UDOT to replace 10-wheel trucks with drop-axle trucks in areas that will be better served with a larger truck.

Snow

The UDOT snow plan relies heavily on the experience of maintenance personnel who perform snow removal activities. Maintenance personnel are responsible for knowing the snow plow routes and performing all snow and ice removal activities. As technology evolves, adjustments are made to routes and plans based on the knowledge and experience of maintenance personnel. UDOT does provide a very high LOS for snow and ice removal activities thanks to the experience of its maintenance personnel. However, a methodology was needed to quantify effects to the LOS due to changes in available resources.

One important outcome of the study was the development of a snow removal model. The snow removal model provides performance measures that allow management to analyze the effect of changes in the availability of equipment or resources. Some important measures calculated by the model are: lane miles per truck, average spread time, and average return time. The power of the model is its ability to provide instant results to planners. The model was a critical component to the QIT as it attempted to quantify the effects of changes in resources on snow removal practices. Table 3 shows the results of a baseline model run for the different regions and districts within UDOT.

Operational Impacts

UDOT maintenance personnel perform many other maintenance tasks on Utah's roadways in addition to snow removal. Some of these tasks are: chip seal projects, lane leveling, paving, shoulder grading, erosion repair, pothole patching, and emergency work. The large truck fleet is used for many of these tasks.

TABLE 3 Snow Removal Model Baseline

Region	Priority	Lane Miles	Total Trucks	Lane Miles/Truck	Average Spread Time	Average Return Time
Region 1	1	1647.2	**89**	**32.2**	2 h 16 min	2 h 24 min
	2	43.6			1 h 45 min	1 h 55 min
	3	799.3			2 h 3 min	2 h 11 min
	4	377.0			5 h 24 min	5 h 36 min
Totals and Averages		**2867.1**			**2 h 37 min**	**2 h 46 min**
Region 2	1	3119.6	**112**	**33.3**	2 h 1 min	2 h 10 min
	2	46.1			1 h 4 min	1 h 12 min
	3	395.2			1 h 50 min	1 h 59 min
	4	171.0			4 h 22 min	4 h 37 min
Totals and Averages		**3731.9**			**2 h 6 min**	**2 h 15 min**
Region 3	1	863.0	**76**	**33.7**	1 h 28 min	1 h 37 min
	2	227.5			1 h 18 min	1 h 26 min
	3	1177.1			1 h 49 min	1 h 58 min
	4	294.5			1 h 43 min	1 h 50 min
Totals and Averages		**2562.1**			**1 h 38 min**	**1 h 47 min**
Richfield	1	332.2	**57**	**39.8**	2 h 9 min	2 h 23 min
	2	0			N/A	N/A
	3	1422.9			2 h 23 min	2 h 33 min
	4	413.0			2 h 47 min	2 h 58 min
Totals and Averages		**2168.1**			**2 h 26 min**	**2 h 37 min**
Price	1	709.8	**58**	**44.7**	3 h 25 min	3 h 38 min
	2	187.6			2 h 8 min	2 h 22 min
	3	1077.8			2 h 41 min	2 h 52 min
	4	614.8			5 h 48 min	6 h 2 min
Totals and Averages		**2590.0**			**3 h 35 min**	**3 h 47 min**
Cedar	1	1023.2	**57**	**45**	1 h 56 min	2 h 4 min
	2	--			N/A	N/A
	3	1055.2			2 h 10 min	2 h 21 min
	4	488.8			2 h 52 min	2 h 58 min
Totals and Averages		**2567.2**			**2 h 12 min**	**2 h 22 min**

The QIT concluded that what drives the size of the large truck fleet is the snow plan. All members of the QIT agreed that for other normally scheduled maintenance activities, as discussed above, UDOT could accomplish the tasks with fewer large trucks. One exception to this is when emergency situations arise. UDOT often encounters emergency situations on its roadways that require the immediate attention of maintenance personnel. Emergency situations range from rockslides to explosions on the roadway. Reducing the size of the large truck fleet would impact the ability of UDOT to respond as quickly and efficiently to emergency situations.

Determining the affects of a reduction in large trucks on maintenance operations is not as easy to quantify as costs or affects to the snow plan. The QIT relied on the expertise of its members to define the impacts and effects of equipment reductions to operations.

Liability

Liability is also difficult to quantify. Liability is critical in evaluating alternatives for reducing the size of the large truck fleet as litigation costs can have a dramatic impact on department resources. The QIT discussed each alternative and identified any significant liability concerns.

QUALITY IMPROVEMENT ALTERNATIVES

As stated previously, the original mandate from UDOT management was to prepare two plans: the first plan would reduce the large truck fleet by 10% and the second plan would reduce the large truck fleet by 20%. In addition to the task of reducing the size of the fleet, the QIT was asked to identify ways to increase the utilization of the remaining trucks in the fleet in order to maintain the same LOS on Utah's roadways. The QIT explored several alternatives to achieve these goals. The following alternatives were explored:

1. Do nothing;
2. Fleet reduction resulting from increased efficiencies;
3. Increase summer utilization;
4. Lease trucks for winter operations;
5. Outsource snow removal to private contractors;
6. Lease UDOT trucks to contractors for summer operations;
7. Outsource snow removal to other public agencies; and
8. Interagency vehicle use.

Each of these alternatives was evaluated using the criteria discussed in the previous section: cost, affect on the snow plan, operational impacts, and liability.

Do Nothing

The "do nothing" alternative establishes a baseline against which other alternatives can be measured. The baseline has been discussed in detail previously. The do nothing alternative also acknowledges the fact that UDOT provides a very high LOS for snow removal and other activities with its current fleet of large trucks.

Fleet Reduction Resulting from Increased Efficiencies

It is important in any quality improvement process to examine current practices and determine areas where improvements can be made and efficiency improved. Each region and district within UDOT examined its operations with regard to the large truck fleet and presented a plan for reducing the number of trucks. Some of the ideas presented were

- Replace a bobtail and a 1-ton crew truck with a 1½-ton truck that could be used as both a crew truck and a snow removal truck in limited areas.

- Mount liquid chemical applicators on a pup-trailer instead of directly on the truck. This allows a traditional sander to remain on the truck and eliminates the need for a separate liquid truck.
- Purchase a large tanker truck that may be used for anti-icing purposes and can replace two or more traditional liquid trucks.
- Purchase truck-mounted attenuators to mount on 10-wheel trucks to replace a designated attenuator truck.
- Eliminate trucks used for traffic control activities and outsource that activity.
- Purchase a multipurpose truck to be used for warehouse supply activities, and snow removal when needed.
- Add additional wings on existing plows.

These were just some of the ideas presented to increase the efficiency of UDOT operations in relation to its large truck fleet. The QIT identified approximately 5% of the UDOT large truck fleet that could be eliminated due to increases in efficiency.

Reducing the number of trucks due to increased efficiency accomplishes the goals established by the QIT. Some costs are associated with the efficiency reductions, but the savings realized from owning and maintaining less equipment should offset those costs. This plan will affect the snow plan as many of the trucks marked for reduction are the "spare" trucks available in the regions and districts. These spare trucks are used to cover for trucks that break down. Affects to other operations and liability should be minimal.

Increase Efficiencies in Summer Vehicle Use

A major concern with the UDOT large truck fleet, and one of the primary reasons the QIT was formed, is that some large trucks are underutilized during summer months. Some trucks in the fleet were not used for an entire summer. The reasons this occurs were discussed previously.

The QIT evaluated summer truck usage and came up with many ideas to help alleviate the problem of underutilization. Some of these ideas include the following.

- Better record keeping on truck repairs. If a truck undergoes major repairs then it should not be labeled as "underutilized."
- Limit the number of maintenance personnel allowed to transfer to construction crews during the summer months. As more maintenance personnel receive experience and training in construction the number of personnel sent to construction in the summer should level out to an acceptable level.
- "Balance" truck usage. Equipment managers should ensure that all trucks are utilized at similar levels. Operators often choose a "favorite" truck leaving other trucks underutilized. Underutilized trucks may also be sent to a chip seal crew during the summer to help balance usage.

Underutilization is an isolated problem within the UDOT large truck fleet. The UDOT standard for acceptable truck usage is 360 h per year. This standard was developed considering the desired life cycle of the vehicles and the tasks they are expected to perform. On average each truck in the UDOT large truck fleet is used 509 h per year. Implementing the ideas discussed should help alleviate the problem of some trucks being over utilized while others are underutilized.

Increasing the efficiency and balance of summer truck usage will not have any noticeable affect on costs, the snow plan, or liability. There should be some positive effects to other operations as equipment is used in a more efficient manner.

Lease Trucks for Snow Removal

The general consensus among members of the QIT is that the snow plan drives the number of trucks needed for maintenance operations. The QIT concluded that summer maintenance operations could be conducted effectively with 10% to 20% fewer trucks. By leasing trucks to supplement the fleet during winter months UDOT could reduce the size of its fleet and still maintain a high LOS for winter operations.

There are many obstacles to implementing a leasing program to supplement the UDOT fleet during winter months. Any third party willing to lease trucks to UDOT during the winter months would also want to lease the same trucks to private contractors during the summer months. UDOT snow removal trucks are equipped with very specialized equipment. Most private contractors use larger trucks than UDOT and may require special equipment in addition to that required by UDOT. This would require that the third party build a “super” truck that is available for use by all parties.

Leasing a truck from a third party for winter operations does not appear to be cost effective at this time. Discussions with third-party contractors have resulted in an estimated cost to lease a truck of about $1,500 a month. Mileage and usage charges would be in addition to this base cost. As mentioned previously UDOT spends approximately $1,200 a month to own and operate its trucks year round. After usage fees are added to the monthly lease rate, UDOT will pay more to lease a truck for 6 months than it pays to own a truck year round.

Outsource Snow Removal to Private Contractors

Another way to supplement the UDOT fleet during the winter months is to hire private contractors to provide snow removal on select routes. This alternative has been implemented successfully in other states. UDOT would maintain the snow removal on major roads and contractors would perform snow removal on lower priority roads. This allows UDOT to reduce the size of its fleet but still maintain snow removal services during winter months.

The largest obstacle to implementing this alternative is again the cost. UDOT may pay a very high premium to hire drivers and trucks and have them on call for snow removal. The New Hampshire DOT outsources approximately 60% of its snow removal activities to private contractors. In discussing this practice with New Hampshire DOT personnel, they have indicated that it is growing increasingly difficult to hire private contractors at the rate the New Hampshire DOT is willing to pay. New Hampshire may actually be nearing a point in time where it needs to determine if it is more cost effective to go back to performing its own snow removal activities.

It also remains to be seen if private contractors can provide the same LOS as UDOT personnel. UDOT personnel have a very real “ownership” of the roads they work on. Because of this ownership, UDOT personnel are very careful in the way they provide snow removal service on the roadways. If a UDOT driver knocks down a sign he will need to go back and replace the sign. Private contractors do not have this "ownership" of the roadway and therefore may not take care of the roadway in the same manner.

Outsourcing select routes may be a feasible alternative. It is an alternative that requires additional research to determine if it can be done in a cost effective manner and to see whether the same LOS could be maintained.

Lease UDOT Trucks to Private Contractors

Leasing UDOT trucks to contractors for summer work presents many of the same problems associated with leasing trucks from contractors. UDOT and the contractor would again need to build a "super" truck that is equipped for snow removal but also large enough and configured properly for a contractor's needs. Leasing trucks to contractors would help reduce the size of the UDOT fleet but there are many liability, and tax issues that may be associated with leasing state equipment to private contractors.

On March 23, 2005, members of the QIT team met with the Associated General Contractors (AGC) to determine if contractors showed any interest in leasing trucks from UDOT. The AGC did not express interest in leasing vehicles. One of the concerns the AGC had with leasing state vehicles is that it would be unfair competition to many of the smaller contractors who only own one or two trucks. The AGC was very concerned that many of these smaller contractors would be put out of business if larger contractors were able to lease state vehicles for summer operations.

UDOT met with the AGC a second time in May and received confirmation from the AGC that they are not interested in leasing UDOT trucks during the summer months. Because of the lack of interest and the issues involved with leasing UDOT vehicles, this option was not explored further at this time.

Outsource Snow Removal to Cities and Counties

UDOT maintains many roads that pass through city and county jurisdictions. In some limited circumstances it may be possible to turn snow removal operations over to the city or county. This is a very site specific option that depends on where roads are located, ability of city or county crews to perform snow removal operations, and the relationship of the road to UDOT snow routes.

Members of the QIT were asked to identify any roads within their jurisdictions that could potentially be turned over to a city or county for snow removal. In doing so the members were asked to consider the items listed above. The members identified many roads that were potential candidates for this "outsourcing" of snow removal activities. Some issues the QIT identified during this process were:

- Turning over roads to cities and counties for snow removal often divides UDOT snow routes into smaller pieces and breaks up continuity of snow removal activities.
- Many of the routes identified were very short segments and would not significantly reduce the effort required by UDOT to perform snow removal operations.
- Cities and Counties approached by members of the QIT generally did not respond favorably to providing this service. If there was any interest the city or county would only be willing to provide the service if UDOT provides the resources to accomplish the task.

These are a few of the issues that arise with the outsourcing of snow removal operations to cities and counties. Cities and counties often ask for more money than UDOT pays to provide the service. This alternative remains open but is not being aggressively pursued due to the issues raised.

Interagency Vehicle Use

The most promising alternative for increasing the efficiency of the UDOT fleet is interagency vehicle use. This alternative is attractive because it does not have a significant affect on the snow plan, and it has the potential to provide significant cost savings to the state by increasing the efficiency of equipment operations.

As has been discussed previously, the QIT has determined that UDOT could lose between 10% and 20% of its fleet in the summer and still accomplish the maintenance tasks required. The main concern with reducing the size of the large truck fleet is a reduced capacity to perform snow removal operations. Other state agencies use equipment heavily during the summer months but do not use the vehicles during winter months. A logical solution to this problem is to create a partnership between UDOT and another state agency in which UDOT will use the trucks during the winter months for snow removal, and the other agency would use the trucks during summer months for its activities.

The agency that appears to be the most likely candidate for an agreement of this type is the Department of Natural Resources (DNR). The DNR maintains a sizeable fleet of dump trucks that it uses for summer work. The dump trucks DNR uses receive very little usage during winter months. An agreement that sends a portion of the UDOT fleet to DNR for summer work appears to be an ideal partnership. On May 31, 2005, the deputy director of UDOT met with the deputy director of DNR and discussed this idea. Both parties were very interested in pursuing an agreement that would lead to a partnership for equipment usage. DNR stated that it may be able to use up to 25 trucks during the summer months.

Other agencies have been identified for research in cooperative equipment agreements including: cities, counties, and the federal government. Establishing agreements with these groups would be much more difficult than establishing an agreement with DNR for the simple reason that both UDOT and DNR are state agencies. For this reason the QIT decided to explore the option of a cooperative agreement with DNR before trying to create any agreements with other agencies.

Reaching an agreement with DNR would potentially save the State of Utah a significant amount of money. UDOT will share the cost of “owning” the trucks with DNR and equipment costs should decrease. A reduction of 25 vehicles in the state’s large truck fleet could potentially save the state approximately $350,000 per year.

CONCLUSIONS AND RECOMMENDATIONS

The equipment QIT has come to the preliminary conclusion that the alternative that will yield the greatest benefits with the lowest impacts to UDOT operations is interagency vehicle use. This alternative achieves all of the objectives the equipment QIT was established to address by increasing summer vehicle utilization, having little or no effect on the snow plan, does not increase liability to UDOT, and does not significantly affect other maintenance operations. It is anticipated that approximately 25 trucks, or about 5% of the current UDOT fleet, could become part of an interagency agreement between UDOT and DNR.

UDOT will continue to work out the details with DNR to reach an agreement and implement this initiative. Once an agreement is in place and UDOT and DNR begin sharing "ownership" of some large trucks, the program will be monitored for effectiveness. If successful, UDOT may be able to look for other state agencies or even city or county agencies to partner with.

The efficiency alternative also offers benefits to UDOT. If UDOT decreases the size of its fleet by increasing the efficiency of its operations, costs should go down, utilization should go up, and the snow plan and other maintenance activities should feel little or no effect. The QIT has already begun to implement some of the efficiency reductions discussed in this report. Table 4 summarizes the changes being made to the UDOT fleet to achieve greater efficiency and reduce the size of the fleet. By making these changes UDOT can reduce the size of its fleet by approximately 26 vehicles or about 5%.

TABLE 4 Fleet Reductions Due to Improved Efficiency

Region or District	Improvements	Trucks Reduced
Region 1	• Four seasonal-use trucks equipped to perform snow removal and other activities. • Eliminate 1½-ton fuel truck and mount fuel and service equipment on a trailer. • Eliminate two traffic control trucks and outsource those services.	**7**
Region 2	• Eliminate epoxy truck and outsource service. • Eliminate two attenuator trucks and equip two snow trucks with attenuators. • Eliminate flat bed truck. • Eliminate flat bed truck with attenuator.	**5**
Region 3	• Equip additional trucks with wing plows. • Redefine routes and implement shift work.	**4**
Richfield	• Eliminate one backup snow removal truck. • Eliminate warehouse supply truck and use other equipment to perform service. • Eliminate one truck from station 4332.	**3**
Price	• Eliminate bobtail attenuator truck. Equip snow truck with attenuator. • Eliminate one additional bobtail and one additional 10-wheeler. • Equip anti icing trucks with sanders and move anti-icing equipment to pup trailers.	**3**
Cedar City	• Equip four non-snow trucks with snow removal equipment creating multi-purpose trucks. • Eliminate four snow removal trucks.	**4**
Total Fleet Reduction		**26**

The original request from UDOT management required the QIT to come up with two plans. The first plan would reduce the size of the UDOT large truck fleet by 10% and the second plan would reduce the size of the fleet by 20%. Each region and district provided these plans and the resulting effects to the snow plan are shown in Table 5.

The combined results of the interagency partnerships and reductions due to increased efficiencies are expected to reduce the size of the fleet by approximately 10%. Implementing these initiatives should have a minimal effect on the current level of service provided as Table 5 illustrates. Making additional cuts to achieve a 20% reduction in fleet size would have more significant impacts.

The snow removal model developed by UDOT can be used to continue to optimize snow removal operations. The model gives planners the ability to model changes to resources and see instant results. The model also provides performance measures that may be used to establish level of service. The model will be a very important tool for UDOT planners as they continue to improve snow removal operations and increase the efficiency and utilization of the large truck fleet.

The final recommendations of the QIT are as follows.

- Continue to pursue interagency vehicle use partnerships and monitor progress.
- Continue implementing reductions in large truck fleet due to increased efficiencies.
- Balance truck usage during summer months.
- Use the snow removal model created as part of the QIT process to continue to optimize the snow plan and improve efficiencies.

Implementing the initiatives discussed in this section greatly improves the efficiency of the UDOT fleet. These initiatives also provide cost savings to both UDOT and DNR. As equipment practices continue to change, UDOT will continue to look for ways to increase the efficiency of its large truck fleet.

TABLE 5 Effect of a 10% and 20% Fleet Reduction on Snow Removal

Region or District	Spread Time			Lane Miles per Truck		
	Current	10% Reduction	20% Reduction	Current	10% Reduction	20% Reduction
Region 1	2 h 37 min	2 h 38 min	2 h 50 min	32.2	32.6	36.8
Region 2	2 h 6 min	2 h 10 min	2 h 17 min	33.3	35.5	39.7
Region 3	1 h 38 min	1 h 49 min	1 h 59 min	33.7	37.7	42.0
Richfield	2 h 26 min	2 h 41 min	2 h 53 min	39.8	42.0	45.4
Price	3 h 35 min	3 h 36 min	3 h 59 min	44.7	45.4	50.8
Cedar City	2 h 10 min	2 h 25 min	3 h 1 min	45.0	46.7	52.4

PART 7

Work Zone Safety and Pavement Markings

Practices to Improve the Safety of Mobile and Short-Duration Maintenance Operations

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The *Manual on Uniform Traffic Control Devices* (MUTCD) provides basic principles that govern the design and use of traffic control devices in work zones. In addition, the Texas Department of Transportation (TxDOT) has three mobile and 15 short-duration traffic control plans that can be used by TxDOT personnel to decide what types of traffic control devices are needed for these operations. In some cases, these traffic control plans have subtle differences. In addition, since these traffic control plans were not all created at the same time there are some inconsistencies.

Due to the subtle differences and inconsistencies among the TxDOT traffic control plans, as well as the need to adapt the information in the MUTCD and TxDOT traffic control plans to specific situations, it is difficult for maintenance personnel (who are not engineers) to make decisions about which traffic control devices are needed on a day-to-day basis for mobile and short duration maintenance operations. In addition, the everyday definitions of mobile and short-duration operations used among TxDOT maintenance personnel are not consistent. With this in mind, researchers examined the terminology currently used to define mobile and short-duration operations and recommended changes, developed maintenance traffic control plans for select mobile and short-duration operations, and developed guidance for choosing whether protection vehicles are needed based on roadway volume (average daily traffic) and posted speed limit.

INTRODUCTION

Maintenance work is often accomplished using mobile or short-duration work zones. Mobile operations typically consist of one or more vehicles that move along the road intermittently or continuously at very slow speeds relative to the normal traffic stream. Short-duration operations involve work that occupies a location for up to 1 h. Both types of operations present a challenge due to the impracticality of installing traffic control devices since it takes longer to set up the traffic control devices than to perform the work activity. Research was needed to identify and evaluate new traffic control devices and practices that could be used to improve the safety of mobile and short-duration maintenance operations.

Recently, the Texas Transportation Institute (TTI) conducted a 2-year research project for the Texas Department of Transportation (TxDOT) to identify and evaluate new traffic control devices and practices that could be used to improve the safety of mobile and short-duration maintenance operations. The first year of research project focused on identifying hazards encountered by both workers and motorists in mobile and short-duration maintenance operations. To accomplish this objective, researchers conducted a survey of state transportation agencies, discussion groups with TxDOT field and supervisory personnel, and field observations of mobile and short-duration operations. Research Report 4174-1 (*1*) documents the findings from these tasks.

The primary hazards identified were apparent motorist misunderstanding of traffic control devices, vehicles entering the work convoy, speed differential between the normal traffic stream and the work convoy, and passing maneuvers around the work convoy on two-lane, two-way roadways. In addition, the information gathered during the first year of the research highlighted the fact that the definitions of mobile and short-duration operations, as well as the classification of specific operations as either mobile or short duration, were not consistent. Also, it is difficult for maintenance personnel (who are not engineers) to make decisions about which traffic control devices are needed for mobile and short duration maintenance operations on a day to day basis. Thus, researchers concluded that there was a need for:

- A clearer distinction between mobile and short-duration operations,
- Guidance in applying standards to specific types of operations, and
- Guidance for the use of "optional" devices based on roadway conditions.

The objective of the second year of the research project was to identify and evaluate new technologies and practices that could be used to improve the safety of mobile and short-duration maintenance operations. Researchers conducted a synthesis of previous research, focus groups, motorist surveys, and a field study to assess motorist comprehension and the operational effectiveness of current and innovative traffic control devices. The findings from these tasks are documented in Research Report 0-4174-2 (*2*). Specifically, this paper documents the efforts of the researchers and TxDOT personnel to

- Examine the terminology used to define mobile and short-duration operations and determine if changes would help distinguish between these types of operations,
- Develop maintenance traffic control plans for select mobile and short-duration operations, and
- Develop guidance for choosing whether protection vehicles are needed based on roadway volume (average daily traffic) and posted speed limit.

BACKGROUND

Many variables, such as type of work, location of the work, road type, road geometry, and traffic volumes, affect traffic control needs at each work zone. A major factor in determining the traffic control devices to be used is work duration. The five categories of work duration are (*3*, *4*, *5*):

- Mobile: work that moves intermittently or continuously;
- Short duration: work that occupies a location up to 1 h;
- Short-term stationary: daytime work that occupies a location for more than 1 h within a single daylight period;
- Intermediate-term stationary: work that occupies a location more than one daylight period up to 3 days, or nighttime work lasting more than 1 h; and
- Long-term stationary: work that occupies a location more than 3 days.

The traffic control that is typically used with short-term stationary, intermediate-term stationary, and long-term stationary operations is relatively extensive since the work zone is semi-permanent and worker exposure to the traffic stream is fairly high. In contrast, the traffic control for mobile and short-duration operations is generally portable and consists of relatively few devices due to the nature of the work area (i.e., short work time or moving work area).

The *Manual on Uniform Traffic Control Devices* (MUTCD) (*3*) and the Texas MUTCD (*4*) support the need for a simplified traffic control procedures for mobile and short-duration operations. In general, both manuals state that mobile and short-duration operations might involve different types of traffic control devices or a reduction in the number of traffic control devices because it often takes longer to set up and remove the devices than to perform the actual work. More specifically, the manuals state that appropriately colored or marked vehicles with rotating–strobe lights may be used in place of signs and channelizing devices. Both manuals also note the importance of the mobility of the traffic control, so that it can be moved periodically as the work progresses. However, these manuals explicitly state that the safety of mobile and short-duration operations should not be compromised by using fewer devices simply because the operation will frequently change locations.

Chapter 6H of both manuals contains typical applications for a variety of situations commonly encountered. While not every situation is addressed, the information provided can be adapted to a broad range of conditions. The minimum procedures are typically illustrated; thus, other devices may be added to supplement the devices depicted. However, as previously discussed under some field conditions, mobile and short-duration operations may use fewer devices. So, applying these guidelines to actual field conditions requires judgment.

In addition to the Texas MUTCD, TxDOT also has three mobile and 15 short-duration traffic control plans (*5*) that can be used by TxDOT personnel to decide what types of traffic control devices are needed for these operations. The mobile traffic control plans address mobile operations on two-lane, two-way roadways, undivided multilane roadways, and divided multilane roadways. The following vehicles and traffic control devices may be used with mobile operations: lead vehicle, work vehicle, shadow vehicle, trail vehicle, yellow rotating beacons or strobe lights, Type B or C arrow panels, truck-mounted attenuators (TMAs), flaggers, channelizing devices, flags, and signs. Based on the prevailing roadway conditions, traffic volume, and sight distance restrictions, the engineer determines if the lead vehicle and/or the trail vehicle are required.

The TxDOT short-duration traffic control plans address short-duration operations on two-way roadways, undivided multilane roadways, and divided multilane roadways. The following vehicles and traffic control devices may be used with short-duration operations: work vehicle, shadow vehicle, rotating lights or strobe lights, arrow panels, portable dynamic message signs, TMAs, flaggers, channelizing devices, flags, and signs. TxDOT uses many of the same standard traffic control plans for short-duration operations and longer duration work (e.g., work that occupies a location for more than 1 h); thus, some of the traffic control plans include fairly complex setups. However, as discussed previously, since it often takes longer to set up and remove the traffic control devices than to perform the actual work, a reduction in the number of traffic control devices may be warranted for short duration operations. Thus, all of the devices listed above are not always used.

STATE SURVEY

The research team conducted a survey of state transportation agencies with regard to mobile and short duration maintenance operations. One of the objectives of the survey was to determine the current practices employed by states during mobile and short duration maintenance operations. The survey was distributed to 49 state transportation agencies (all except Texas) using e-mail. Responses were received from 17 states, representing a return rate of 35%.

Definitions of Mobile and Short-Duration Operations

The majority of the responding states indicated that their definitions of mobile and short-duration operations were consistent with those provided in the MUTCD. However, there were some cases in which the definitions varied from those in the MUTCD. For mobile operations, the Oregon DOT definition contained no reference to intermittent stops. Thus, the Oregon DOT defines mobile operations as continuously moving operations only. It was also noted that in different states, snow and ice removal were either specifically included in a state's examples of mobile operations (Alaska and Nevada DOTs) or specifically excluded from the mobile definition (Illinois DOT).

The short duration operation definitions varied from allowing less than 15 min of work (Oregon DOT) to work that lasts up to 12 h (Maryland DOT). For the Nevada DOT, their definition agrees with the MUTCD; however, the survey indicates that the agency acknowledges that the work categorized in this area could take several hours. One interesting note made by several states is that the work encompassed by the definition of short duration can frequently take a shorter amount of time to complete than to set up and remove the appropriate traffic control devices. Interestingly, the short duration criteria established for the Florida DOT falls within the mobile operations definition. In this case, the Florida DOT considers work with intermittent stops as short-duration work.

One particularly unusual case identified was the definitions utilized by the New York DOT. Three categories of work were included in the responses from the New York DOT: mobile, slow moving, and short-duration stationary operations. The three work categories were aligned with the MUTCD definitions using examples of work provided by the New York DOT:

- Mobile: Although the term mobile was used as a descriptor, the activities defined under this category (debris pickup, signal lamp change, traffic counter installation) were more closely related to the MUTCD definition of short-duration operations. Researchers believe that this work is termed "mobile" within New York due to the fact that the operation does not occupy one site for a significant period of time.
- Slow moving: The work activities defined within this category are those in which special equipment or workers on foot in the roadway are moving at a slow pace (pouring cracks, pavement overlay). In this evaluation, these operations align with the MUTCD definition of mobile maintenance operations.
- Short-duration stationary: These activities are considered to be any work that would occupy an area for greater than a brief period (installing signs, guard rail repair, patching pavement). Again, this falls within the definition of the MUTCD short-duration operations; however, the time allowed under the New York DOT activities can be up to 1 working day (i.e., 8 h).

Current Practices for Mobile and Short-Duration Maintenance Operations

Of the states that responded, all have defined procedures and plans for mobile and short-duration maintenance operations. The most common response was that the standards and plans were compliant with those set by the MUTCD. In addition, all responding states indicated that they have standard traffic control plans for mobile maintenance operations, and all but one of the responding states indicated that they have standard traffic control plans for short-duration maintenance operations. The state that does not have specific standards for short-duration operations (Connecticut) leaves it to the general supervisors of the maintenance crews to use their best judgment and simplify the standard traffic control plans used for longer duration work zones to fit the current situation. In the case of both mobile and short-duration maintenance operations, the procedures outlined by the responding states are, for the most part, consistent with the current practices of TxDOT.

Beyond these basic guidelines, 12 of the responding states have also created maintenance or safety manuals that address the issue of common procedures for mobile and short-duration maintenance operations and worker safety. Within these manuals, the states address a variety of issues with the common components being:

- General guidelines (taper lengths, buffer zones, traffic control devices, etc.),
- Flagger instruction, and
- Work zone diagrams or layouts.

The work area diagrams presented in the manuals are typically broken into sections based on the type of roadway and the effected area of the roadway (i.e., shoulder, lane, center lane) instead of by duration of work. However, most of the manuals address mobile operations as a separate issue. In the mobile operations sections, work is again typically separated based on the roadway type and the effected area of the roadway. One point of interest within this section is that several of the manuals provided diagrams for specific operations such as

- Striping,
- Mowing and chemical treatment (herbicide), and
- Pothole and edge patching.

There are a few points of interest that stood out within the manuals provided by the states. In the Illinois DOT diagrams, daily speed of the operation is a deciding factor in selecting traffic control for mobile operations. If the operation is moving less than 4 mi per day, the work zone setup requires a greater number of signs.

Included with the Maryland DOT guidelines for traffic control are device selection charts. The charts identify the required and optional devices based on roadway type, work location, roadway speed, and work duration.

The short-duration and mobile operations diagrams from the Michigan DOT included information on speed reductions. In this case, speed reduction signs are located on the shadow vehicles. The Michigan DOT also provided a list of considerations regarding the use of optional shadow vehicles. The shadow vehicles are considered mandatory for any lane closure on roads with speeds greater than 55 mph; however, shadow vehicle use in other work situations is based on the following factors:

- Time of day,
- Seasonal traffic volume variations,
- Length and duration of lane closure,
- Roadway speed, and
- Vehicle behaviors (i.e., stopping and turning).

TxDOT DISCUSSION GROUPS

Researchers held seven discussion groups which targeted two different segments of TxDOT personnel: field personnel (i.e., employees who perform maintenance activities on a day-to-day basis) and supervisory personnel (i.e., area engineers and maintenance supervisors). In total, 114 TxDOT personnel participated.

The primary objectives of the focus groups were to identify the hazards encountered by TxDOT personnel during mobile and short-duration maintenance operations, as well as to stimulate new ideas and creative concepts that could improve worker and motorist safety. However, it became evident that the definitions of mobile and short-duration operations used by TxDOT personnel were diverse and not always consistent with the MUTCD definitions.

Many participants defined mobile operations as work that does not stop on the roadway or is continuously moving along the roadway. In other words, mobile operations do not include work that moves intermittently. In relation to short-duration operations, the participants provided a wide range of time periods (from 15 min to 2 weeks); however, the majority of the participants classified short-duration operations as work that takes 1 day or less to complete.

These variations in the definitions of mobile and short-duration operations make it difficult for field personnel to select the proper traffic control for maintenance operations. Participants indicated a need to create a greater distinction between mobile and short-duration operations, as well as to provide guidance with respect to the application of standards to specific operations. In addition, participants indicated a desire to have guidelines concerning the use of optional devices based on traffic volume or roadway speed.

PRACTICES TO IMPROVE THE SAFETY OF MOBILE AND SHORT-DURATION MAINTENANCE OPERATIONS

Terminology Used to Define Mobile and Short-Duration Operations

The information gathered during the first year of the research revealed that the definitions of mobile and short-duration operations used by TxDOT personnel, as well as other state DOT personnel, were diverse and not always consistent with the MUTCD definitions. These variations in the definitions make it difficult for field personnel to select to proper traffic control for maintenance operations. Thus, researchers felt that there was a need for a clearer distinction between the definitions of mobile and short duration operations.

Some of the uncertainty about which operations are considered mobile and which operations are considered short duration may be due to the use of the word “work” in the definitions. For example, a long-term stationary operation (e.g., adding new lanes to a roadway) may contain “work” that moves intermittently or continuously (e.g., paving). To help distinguish between the types of operations, researchers recommend that the duration be associated with the "temporary traffic control zone" instead of the "work" being performed. A "temporary traffic control zone" is an area of a roadway where the conditions are changed using temporary traffic control devices. Thus, to be considered a mobile operation the "temporary traffic control zone" would have to move intermittently or continuously. If the "temporary traffic control zone" is stationary (independent of whether the "work" is moving), the operation is not considered a mobile operation.

Another issue raised during the first year of this research project concerned the amount of time a mobile operation can be stopped before it is considered a short-duration operation. Several states, as well as one of the TxDOT Barricade and Construction Standard Sheets (*6*), specify that a mobile operation cannot stop for more than 15 min. Likewise, researchers feel that short duration operations are stationary operations and thus should include the "stationary" descriptor in the duration definition.

To help maintenance personnel distinguish between mobile and short duration operations, researchers recommend the following changes to the work duration definitions (deletions are shown as strikeouts and additions are underlined):

- Mobile is ~~work~~ <u>a temporary traffic control zone</u> that moves intermittently <u>(stops up to 15 min)</u> or continuously.
- Short-duration <u>stationary</u> is ~~work~~ <u>a temporary traffic control zone</u> that occupies a location up to 1 h.
- Short-term stationary is <u>a</u> daytime ~~work~~ <u>temporary traffic control zone</u> that occupies a location for more than 1 h within a single daylight period.
- Intermediate-term stationary is ~~work~~ <u>a temporary traffic control zone</u> that occupies a location more than one daylight period up to 3 days, or nighttime work lasting more than 1 h.
- Long-term stationary is ~~work~~ <u>a temporary traffic control zone</u> that occupies a location more than 3 days.

Development of Maintenance Traffic Control Plans

Mobile Operations

Based on existing TxDOT traffic control plans, field observations of mobile operations conducted during the first year of the research project, findings from the second year of the research project, and input from the TxDOT advisory panel, researchers developed maintenance traffic control plans for the following mobile operations:

- Striping,
- RPM installation–removal,
- Shoulder texture,
- Spot pothole patching,
- Spot edge repair,
- Sweeping,
- Herbicide,
- Retroreflectivity measurements,
- Core sampling,

- Temporary tab placement–removal,
- Short-line striping, and
- In-lane (lateral) rumble strips.

For striping, RPM installation–removal, shoulder texture, and other similar types of operations, researchers developed two mobile maintenance traffic control plans: one for undivided highways (Figure 1) and one for divided highways (Figure 2). Both of these maintenance traffic control plans were based on the current TxDOT traffic control plans for mobile operations (*5*). Important items to note include:

- A shadow vehicle is required under all conditions;
- A lead vehicle is required when the work vehicles are working on the centerline of undivided highways;
- The engineer still determines if the lead vehicle or trail vehicle are required based on prevailing roadway conditions, traffic volume, and sight distance restrictions;
- The use of yellow rotating beacons or strobe lights on vehicles are required unless otherwise indicated;
- All protection vehicles (trail, shadow, and lead) are required to have an arrow panel;
- TMAs are required on shadow and trail vehicles; and
- "# VEHICLE CONVOY" sign required on the first vehicle encountered by motorists (either the trail or shadow vehicle).

Researchers developed two mobile maintenance traffic control plans for spot pothole patching, spot edge repair, sweeping, herbicide, retroreflectivity measurements, core sampling, tab placement–removal, and other similar operations (Figures 3 and 4, respectively). These two mobile maintenance traffic control plans are similar to Figures 1 and 2 with the following differences.

- Trail, lead, and advance warning vehicles are not required.
- The engineer determines if the shadow vehicle is required based on prevailing roadway conditions, traffic volume, and sight distance restrictions.
- When a shadow vehicle is not used, herbicide trucks and sweepers are required to have an arrow panel.

Based on a traffic control plan from the TxDOT Tyler District, researchers developed the mobile maintenance traffic control plan in Figure 5 for short-line striping and in-lane (lateral) rumble strips on undivided roadways. Important items to note include

- A shadow vehicle is required;
- The use of yellow rotating beacons or strobe lights on vehicles are required unless otherwise indicated; and
- The shadow vehicle is required to have a TMA and an arrow panel.

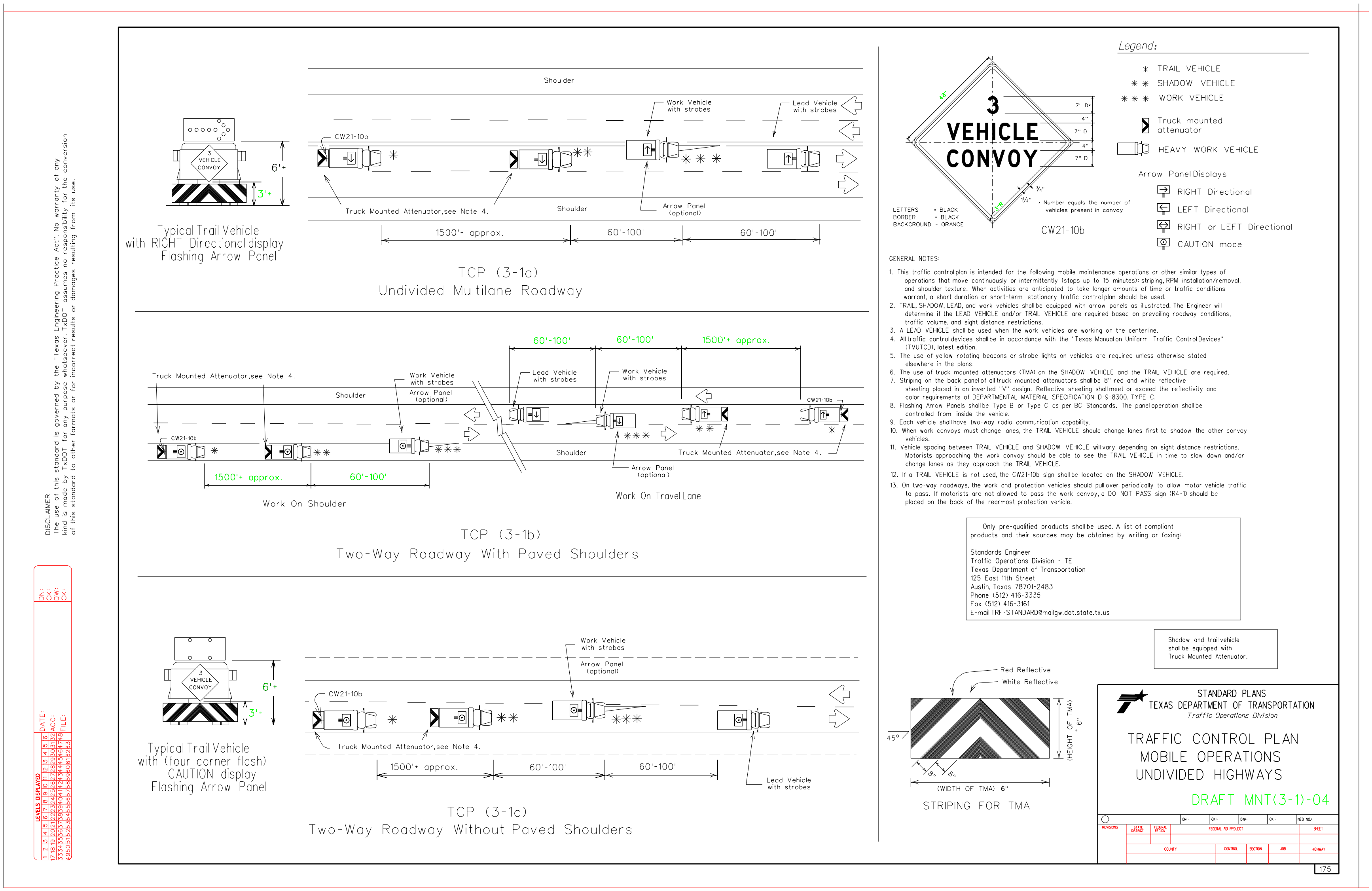


FIGURE 1 Mobile maintenance traffic control plan for striping, RPM installation–removal, shoulder texture, and other similar operations on undivided highways.

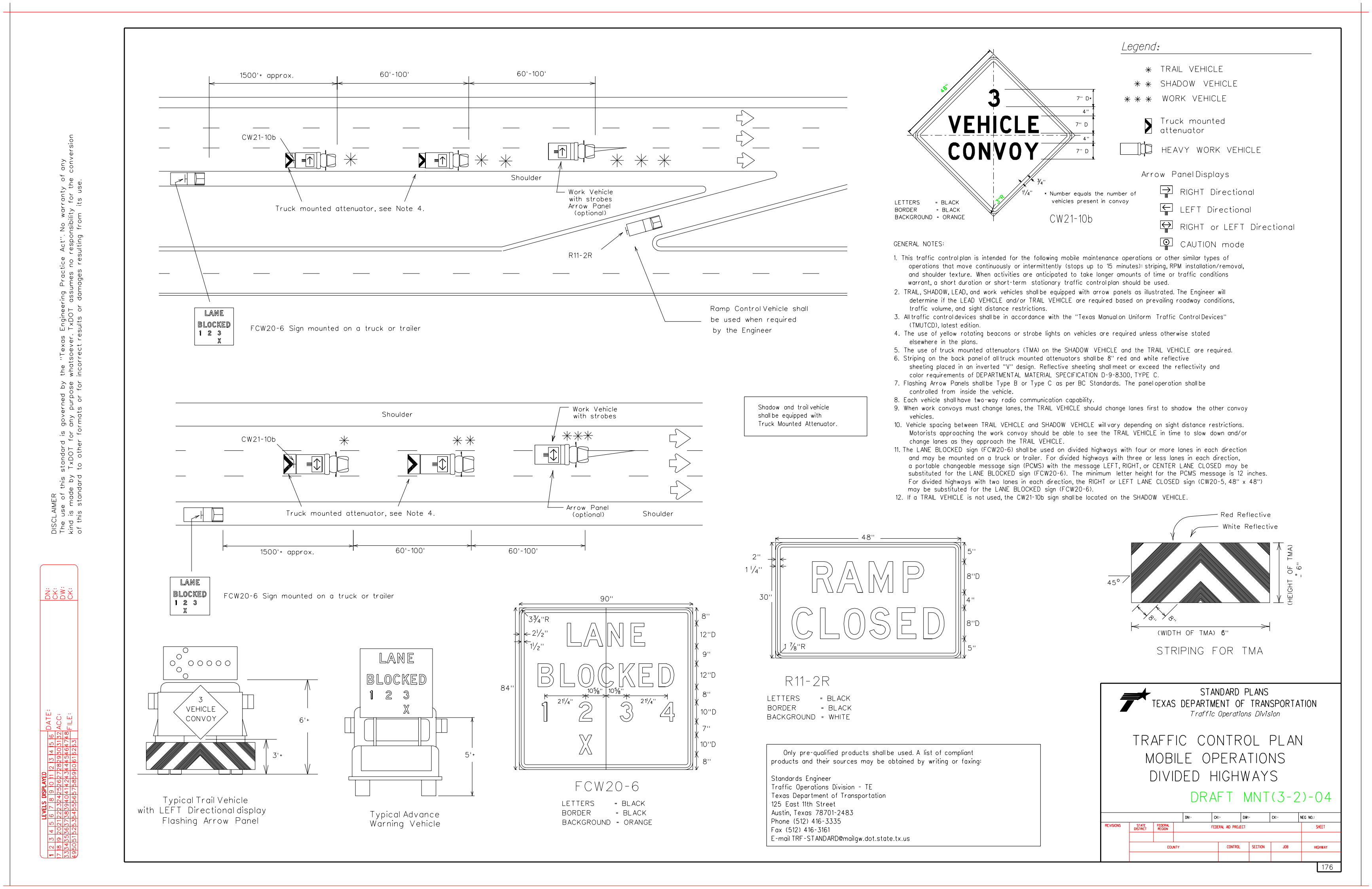


FIGURE 2 Mobile maintenance traffic control plan for striping, RPM installation–removal, shoulder texture, and other similar operations on divided highways.

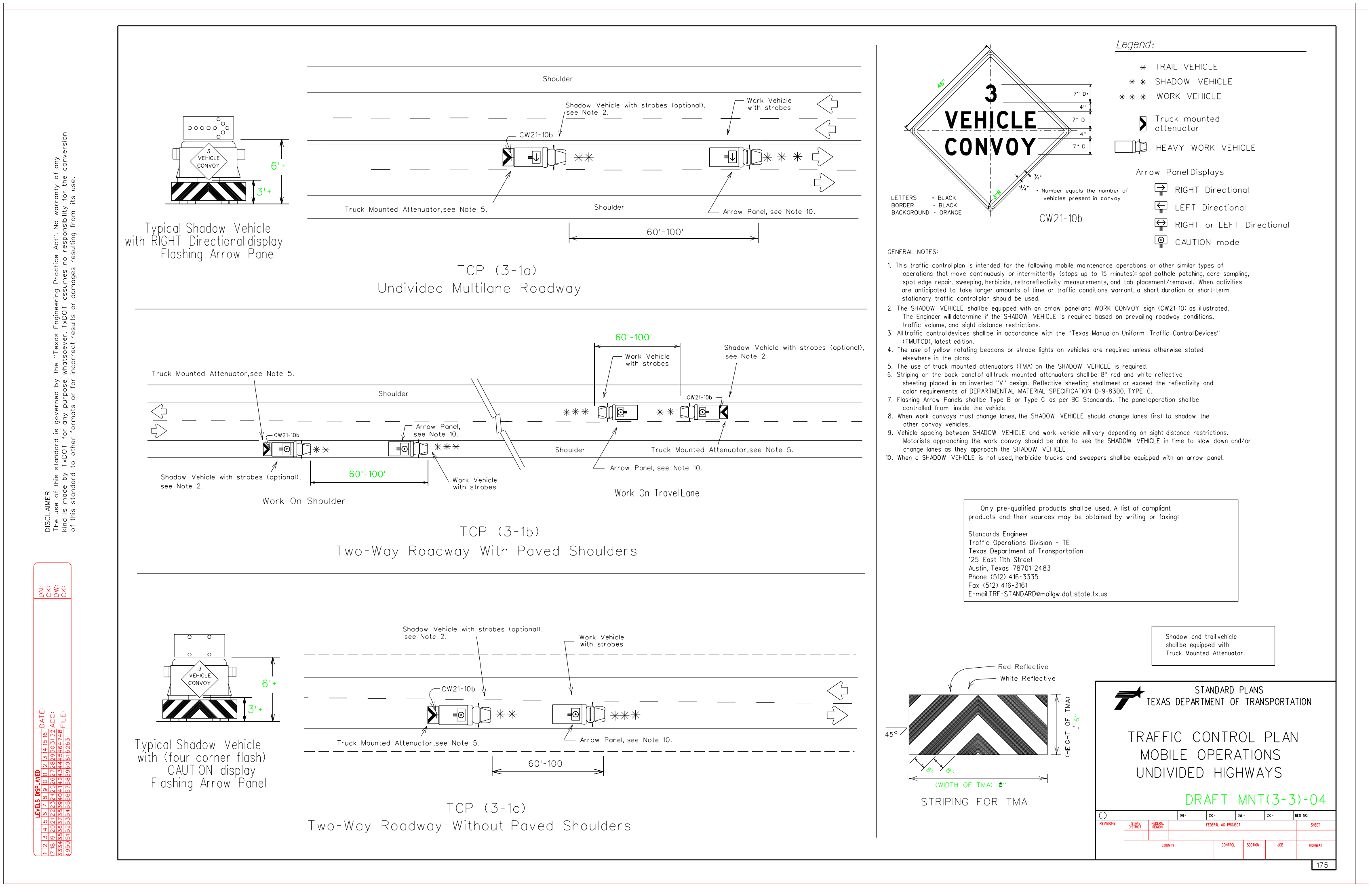


FIGURE 3 Mobile maintenance traffic control plan for spot pothole patching, spot edge repair, sweeping, herbicide, retroreflectivity measurements, core sampling, tab placement–removal, and other similar operations on undivided highways.

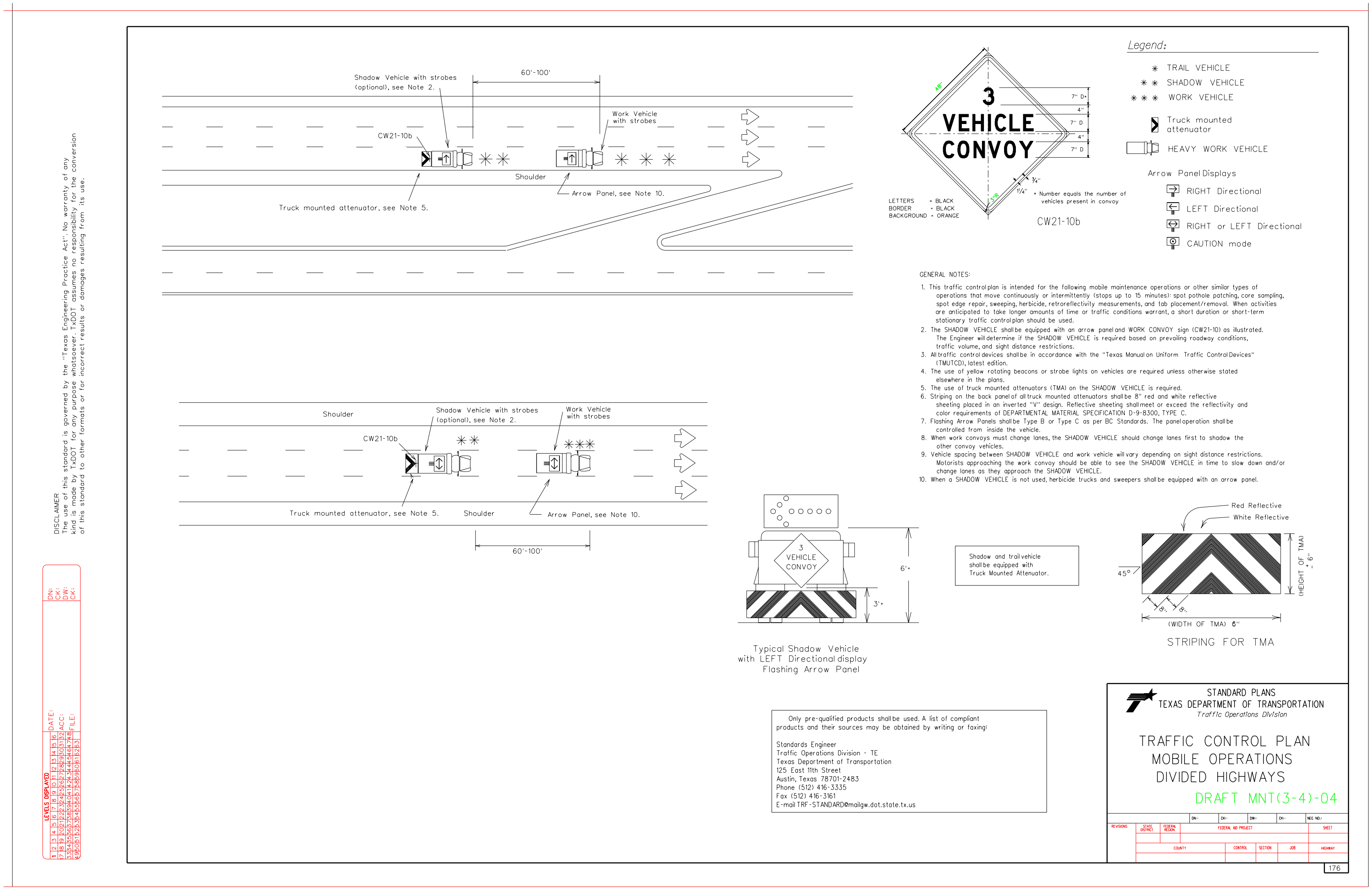
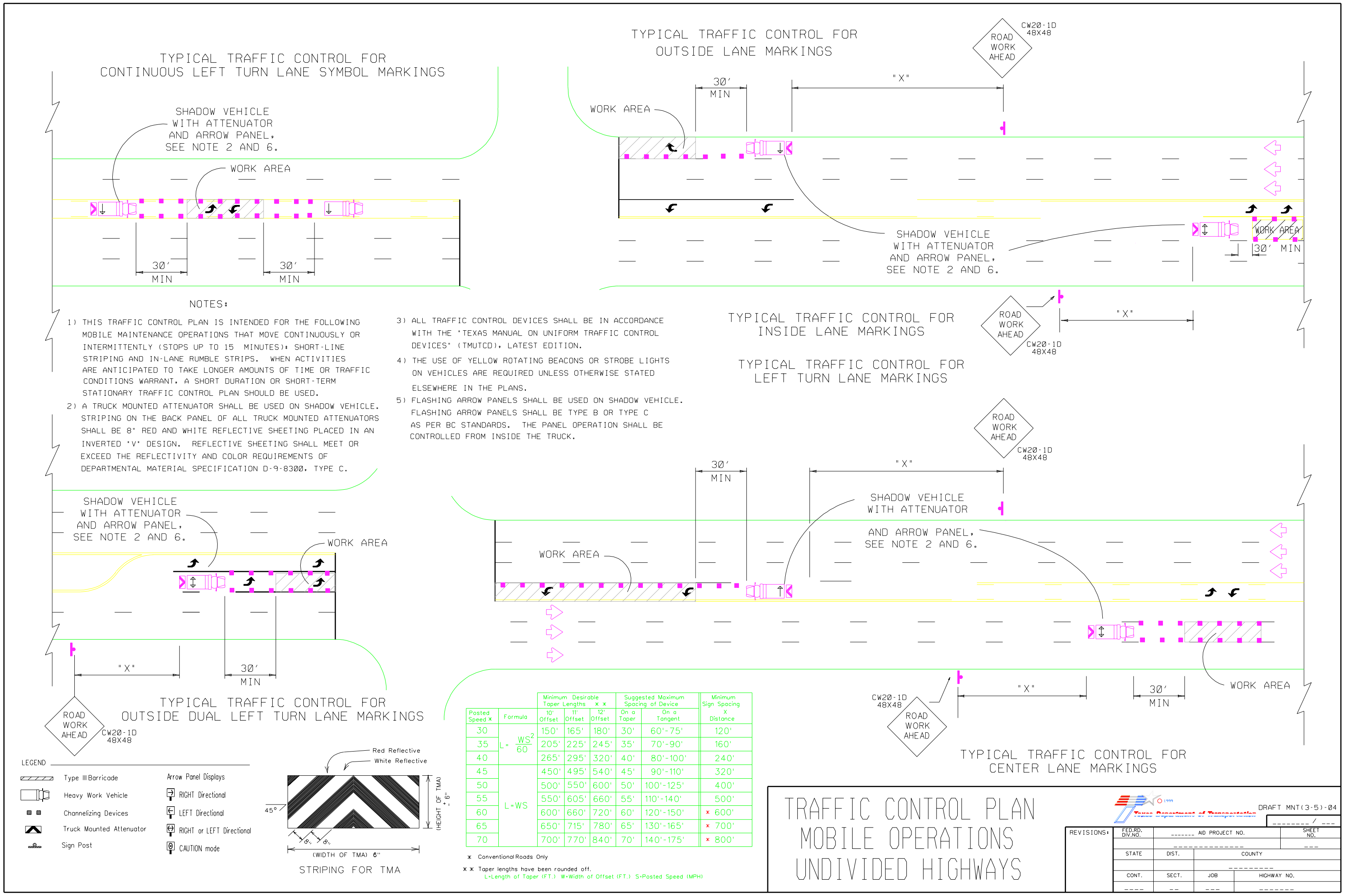


FIGURE 4 Mobile maintenance traffic control plan for spot pothole patching, spot edge repair, sweeping, herbicide, retroreflectivity measurements, core sampling, tab placement–removal, and other similar operations on divided highways.



Posted Speed *	Formula	Minimum Desirable Taper Lengths ** 10' Offset	11' Offset	12' Offset	Suggested Maximum Spacing of Device On a Taper	On a Tangent	Minimum Sign Spacing X Distance
30	$L = \frac{WS^2}{60}$	150'	165'	180'	30'	60'-75'	120'
35		205'	225'	245'	35'	70'-90'	160'
40		265'	295'	320'	40'	80'-100'	240'
45	L=WS	450'	495'	540'	45'	90'-110'	320'
50		500'	550'	600'	50'	100'-125'	400'
55		550'	605'	660'	55'	110'-140'	500'
60		600'	660'	720'	60'	120'-150'	* 600'
65		650'	715'	780'	65'	130'-165'	* 700'
70		700'	770'	840'	70'	140'-175'	* 800'

* Conventional Roads Only

** Taper lengths have been rounded off.

L=Length of Taper (FT.) W=Width of Offset (FT.) S=Posted Speed (MPH)

FIGURE 5 Mobile maintenance traffic control plan for short-line striping and in-lane (lateral) rumble strips on undivided highways.

It should be noted that if any of these mobile operations are not continuously moving, are stopped for longer than 15 min, or traffic conditions warrant, a short duration or short-term stationary traffic control plan should be used.

Short-Duration Operations

Based on TxDOT Traffic Control Plan (1-1)-98 (*5*), field observations of short-duration operations conducted during the first year of the research project, and input from the TxDOT advisory panel, researchers developed the maintenance traffic control plan in Figure 6 for the following short-duration operations: sign, delineator, and lighting maintenance.

This short-duration maintenance traffic control plan is for work being performed on or adjacent to the shoulder and can be used for other similar operations. Work requiring full lane closures should not utilize this maintenance traffic control plan. Important items to note include

- The engineer determines if the advance warning sign or channelizing devices are required based on prevailing roadway conditions, traffic volume, and sight distance restrictions; and
- The use of yellow rotating beacons or strobe lights on vehicles are required unless otherwise indicated.

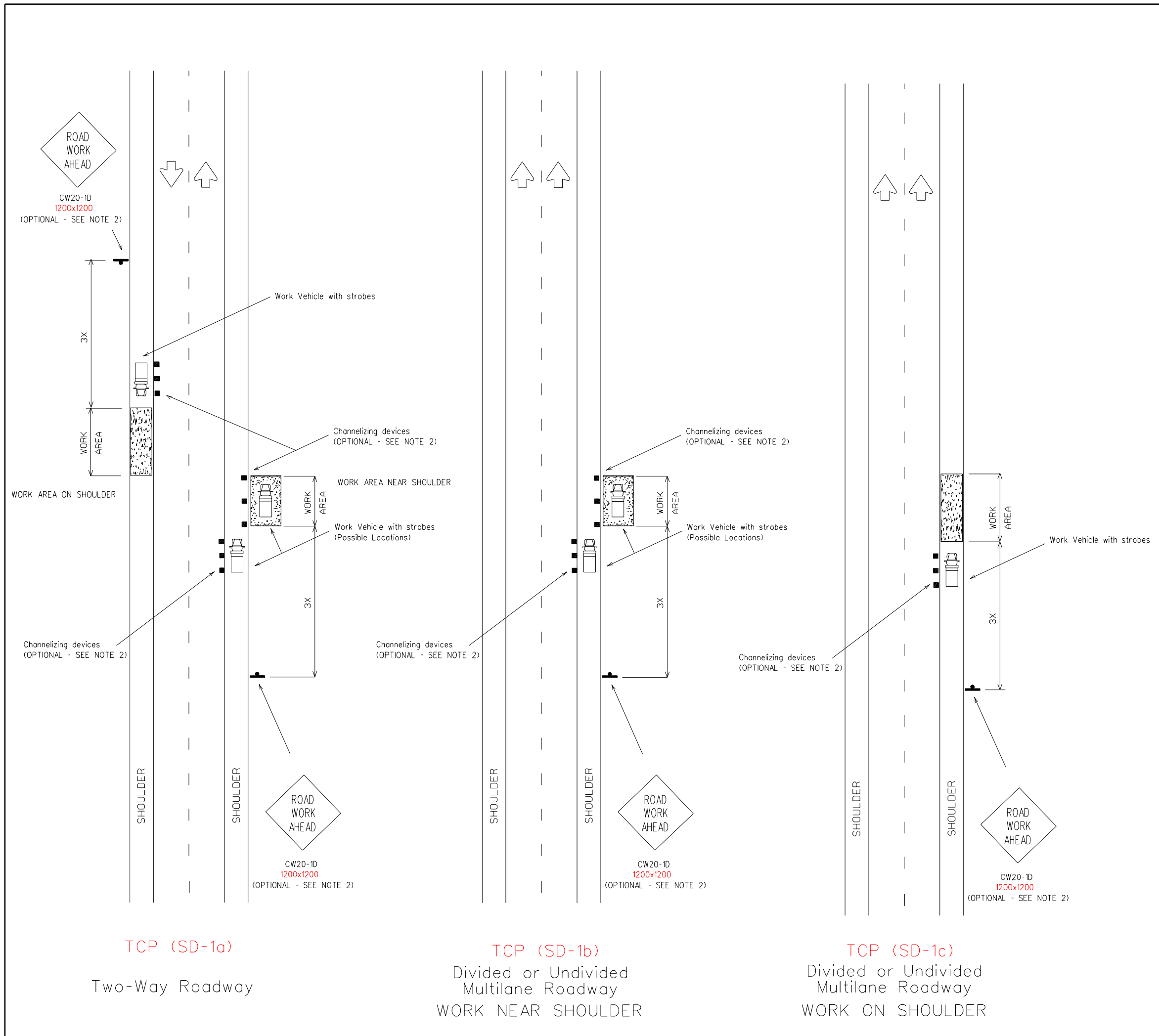
Guidance for the Use of "Optional" Devices

In the MUTCD, Texas MUTCD, and TxDOT traffic control plans several of the traffic control devices for mobile operations are "optional." Based on information received during the first year of the research project and input from the advisory panel, researchers developed guidance for the use of some of these "optional" devices based on the roadway volume [average daily traffic (ADT)] and posted speed.

Currently, there is no standard threshold value that separates low-volume roadways from high-volume roadways. This is also true with respect to low-speed versus high-speed roadways. Researchers reviewed previous literature and other states' work zone manuals to help determine these threshold values. Table 1 contains the findings with respect to volume, while Table 2 contains the findings with respect to speed. Based on these findings and input from the TxDOT advisory panel, researchers utilized the following definitions:

- Low volume: < 2,000 ADT,
- High volume: ≥ 2,000 ADT,
- Low speed: ≤ 45 mph, and
- High speed: > 45 mph.

Researchers worked with the advisory panel to create Tables 3 and 4. Table 3 contains guidance for choosing whether a trail vehicle is needed on striping, RPM installation–removal, and shoulder texture operations (Figures 1 and 2). Similarly, Table 4 provides guidance for choosing whether a shadow vehicle is needed on spot edge repair, spot pothole patching, herbicide, sweeping, retroreflectivity measurements, core sampling, and tab placement–removal (Figures 3 and 4).



LEGEND

Type III Barricade — Channelizing Devices — Flag
Heavy Work Vehicle — Truck Mounted Attenuator
Trailer Mounted Flashing Arrow Panel — Portable Changeable Message Sign
Flagger — Sign Post

Posted Speed *	Formula	Minimum Desirable Taper Lengths ** 3.0 m Offset (meters)	3.3 m Offset (meters)	3.6 m Offset (meters)	Suggested Maximum Spacing of Device On a Taper (meters)	On a Tangent (meters)	Minimum Sign Spacing "X" Distance (meters)
30	$L = \frac{WS^2}{60}$	45	50	55	9	15-20	40
35		65	70	75	10	20-25	50
40		80	90	100	12	25-30	75
45	L=WS	135	150	165	13	25-30	100
50		150	165	180	15	30-35	120
55		165	185	200	16	35-40	150
60		180	200	220	18	40-45	* 180
65		195	215	235	19	40-50	* 210
70		210	235	255	20	40-50	* 240

* Conventional Roads Only
** Taper lengths have been rounded off.

L=Length of Taper (m) W=Width of Offset (m) S=Posted Speed (MPH)

TYPICAL USAGE:				
MOBILE	SHORT DURATION	SHORT TERM STATIONARY	INTERMEDIATE TERM STATIONARY	LONG TERM STATIONARY
	✓			

GENERAL NOTES:

1. This traffic control plan is intended for the following short duration operations or other similar types of operations that occur on or adjacent to the shoulder: sign maintenance, delineator maintenance, and lighting maintenance.
2. The Engineer will determine if the advance warning sign and/or channelizing devices are required based on prevailng roadway conditions, traffic volume, and sight distance.
3. When advance warning signs are required, on high speed facilities advance warning signs should be installed approximately 3X from the work area. On low speed facilities the advance warning signs shoulde be placed on the "X" minimum distance.
4. The use of yellow rotating beacons or strobe lights on vehicles are required unless otherwise stated elsewhere in the plans.

Only pre-qualified products shall be used. A list of compliant products and their sources may be obtained by writing or faxing:

Standards Engineer
Traffic Operations Division - TE
Texas Department of Transportation
125 East 11th Street
Austin, Texas 78701-2483
Phone (512) 416-3335
Fax (512) 416-3161
E-mail TRF-STANDARD@mailgw.dot.state.tx.us

The requirement for shadow vehicles will be listed in the project GENERAL NOTES, Item 502, Barricades, Signs and Traffic Handling.

All dimensions are in millimeters unless otherwise noted.

STANDARD PLANS
TEXAS DEPARTMENT OF TRANSPORTATION

TRAFFIC CONTROL PLAN
SHORT DURATION OPERATIONS

DRAFT MNT(3-6)-04

Metric 151

DISCLAIMER
The use of this standard is governed by the "Texas Engineering Practice Act". No warranty of any kind is made by TxDOT for any purpose whatsoever. TxDOT assumes no responsibility for the conversion of this standard to other formats or for incorrect results or damages resulting from its use.

FIGURE 6 Short-duration maintenance traffic control plan for sign maintenance, delineator maintenance, lighting maintenance, and other similar operations on or adjacent to the shoulder.

TABLE 1 Low-Volume Definitions

Entity/Reference	Low-Volume Definition
Washington State DOT (*7*)	< 10,000 ADT
Illinois DOT (*8*)	< 5,000 ADT
North Carolina DOT (*9*)	≤ 5,000 ADT
TxDOT Research Project 0-4048 (*10*)	< 2,000 ADT
NCHRP Report 362 (*11*)	< 2,000 ADT
Louisiana DOT (*12*)	< 1,500 ADT
Oregon DOT (*13*)	≤ 500 ADT
Wisconsin DOT (*14*)	≤ 500 ADT
2003 MUTCD[1] (*3*)	< 400 AADT

[1] The MUTCD definition of a low-volume road does not include roads on a designated state highway system.

TABLE 2 Low-Speed Definitions

Entity/Reference	Low-Speed Definition
Illinois DOT (*8*)	≤ 45 mph
Green Book (*15*)	≤ 45 mph
TxDOT *Roadway Design Manual* (*16*)	≤ 45 mph
Oregon DOT (*13*)	< 45 mph
2003 Texas MUTCD Work Zone Taper Length Calculations[1] (*4*)	≤ 40 mph
Maryland DOT (*17*)	≤ 40 mph
Washington State DOT (*7*)	≤ 35 mph

[1] Above 40 mph the formula to calculate the work zone taper length changes.

TABLE 3 Guidance for Choosing Whether a Trail Vehicle Is Needed on Striping, RPM Installation–Removal, and Shoulder Texture Operations

Volume (ADT)	Speed (mph)	Two-Lane, Two-Way	Multilane Undivided	Multilane Divided
< 2,000	≤ 45	No	No	No
< 2,000	> 45	No	No	No
≥ 2,000	> 45	Yes	Yes	Yes
≥ 2,000	≤ 45	No	No	No

TABLE 4 Guidance for Choosing Whether a Shadow Vehicle Is Needed on Spot Edge Repair, Spot Pothole Patching, Herbicide, Sweeping, Retroreflectivity Measurements, Core Sampling, and Tab Placement–Removal

Volume (ADT)	Speed (mph)	Two-Lane, Two-Way	Multilane Undivided	Multilane Divided
< 2,000	≤ 45	No	No	No
< 2,000	> 45	No[2]	No[2]	Yes[1]
≥ 2,000	> 45	Yes[1]	Yes[1]	Yes[1]
≥ 2,000	≤ 45	No[2]	No[2]	No[2]

[1] The shadow vehicle may be omitted if the work vehicle does not encroach into a travel lane. However, a shadow vehicle is recommended when a tractor sweeper is used even if it does not encroach into a travel lane.
[2] A shadow vehicle is recommended when a tractor sweeper is used.

It is important to note that the guidance provided in these tables is not based on a crash analysis. Instead, researchers utilized observational data collected during the first year of the research project and input from the TxDOT advisory panel to develop the tables. Even if a crash analysis would have been within the scope of this project, several factors limit the use of crash data with respect to determining when a trail or shadow vehicle should be used. First, existing crash databases do not decipher between the types of work zones (i.e., mobile, short duration, short-term stationary, intermediate-term stationary, and long-term stationary). Second, existing crash databases do not include a description of the traffic control devices used (e.g., whether or not a shadow vehicle was used). Third, the likelihood of establishing accurate traffic exposure numbers during maintenance activities is low since few, if any, existing crash databases include the actual traffic volumes through the work zone. Also with respect to exposure, estimates of the number and type of maintenance operations conducted on a yearly basis are not readily available.

RECOMMENDATIONS

To improve the safety of mobile and short duration maintenance operations, researchers recommended that TxDOT implement:

- The changes to the work duration definitions to help maintenance personnel distinguish between the two types of operations,
- The mobile and short duration maintenance traffic control plans developed as part of the research, and
- The guidance for choosing whether protection vehicles are needed based on roadway volume (average daily traffic) and posted speed limit.

While these “generic” traffic control plans and guidelines provide additional information with respect to selecting traffic control devices for specific mobile and short-duration maintenance operations, researchers recommended that each TxDOT district tailor these guidelines with respect to the characteristics of the roadways in their area. Refinement of the guidelines by each district is the critical “next step” in implementing these recommendations which will aid local maintenance personnel who sometimes have difficulty making decisions about which traffic control devices are needed for the multiple types of maintenance operations they conduct on a day to day basis.

In September 2005, TTI and TxDOT began an implementation project designed to improve and facilitate the adoption of these procedures by the TxDOT districts. Thru this project, TTI will help five TxDOT districts tailor the recommended maintenance traffic control plans and guidelines with respect to the characteristics of the roadways in their area. Researchers will document the implementation process in order to show other TxDOT districts how the five districts refined and implemented the recommendations.

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REFERENCES

1. Ullman, B. R., M. D. Finley, and N. D. Trout. *Identification of Hazards Associated with Mobile and Short Duration Work Zones*. Report 4174-1. Texas Transportation Institute, College Station, September 2003.
2. Finley, M. D., B. R. Ullman, and N. D. Trout. *Traffic Control Devices and Practices to Improve the Safety of Mobile and Short Duration Maintenance Operations*. Report 0-4174-2. Texas Transportation Institute, College Station, December 2004.
3. *Manual on Uniform Traffic Control Devices*, 2003 Edition Revision 1. FHWA, U.S. Department of Transportation, November 2004.
4. *Texas Manual on Uniform Traffic Control Devices*. Texas Department of Transportation, Austin, 2003.
5. Standard Plans Texas Department of Transportation: Traffic Control Plans. Texas Department of Transportation, Austin, 1998.
6. *Barricade and Construction Standard Sheets*. BC(4)-03. Texas Department of Transportation, Austin, November 2002.
7. *Work Zone Traffic Control Guidelines*. Washington State Department of Transportation, May 2000.
8. *Work Site Protection Manual.* Illinois Department of Transportation, July 2000.
9. *Moving Operation Caravan Drawing 4 and 5.* North Carolina Department of Transportation, July 2002.
10. Fitzpatrick, K., A. H. Parham, M. A. Brewer, and S. Miaou. *Low-Cost Design Safety Improvements for Rural Highways*. Report 0-4048-1. Texas Transportation Institute, College Station, October 2001.
11. Zegeer, C. V., R. Stewart, T. R. Neuman, and F. Council. *NCHRP Report 362: Roadway Widths for Low-Traffic Volume Roads*. TRB, National Research Council, Washington, D.C., 1994.
12. *Maintenance Traffic Control Handbook*. Louisiana Department of Transportation, 1990.
13. *Traffic Control on State Highways for Short Term Work Zones*. Oregon Department of Transportation, 1998.
14. *Work Zone Safety Guidelines for Construction, Maintenance, and Utility Operations*. University of Wisconsin–Madison, January 1999.
15. *A Policy on Geometric Design of Highways and Streets*. American Association of State Highway and Transportation Officials, 2001.
16. *Roadway Design Manual*. Texas Department of Transportation, Austin, February 2004.
17. *Temporary Traffic Control (T.T.C.) Supplemental Guide for Short-Term and Mobile Work Operations*. Maryland Department of Transportation, July 1997.

Waterborne Traffic Paint Performance in Utah Based on Retroreflectivity

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The Utah Department of Transportation (UDOT) performed a study to collect pavement marking retroreflectivity data that will provide a better understanding of the impact of waterborne traffic paint on exposure to traffic and other road activities. In 2002, UDOT upgraded its waterborne traffic paint specification to adopt the newest durable waterborne paint technology. At the same year, UDOT began a 3-year study to determine when roads of low, medium, and high average annual daily traffic (AADT) should be repainted based on the retroreflectivity values of the new paint. The failure criterion for the paint is a retroreflectivity value of 100 millicandelas per square meter per lux (mcd/m^2/lx), which is a commonly used value in practice. Several state routes were selected for collecting retroreflectivity data throughout the duration of the study. A mobile retroreflectometer was used to collect retroreflectivity readings periodically from the time of initial roadway painting until the time of assumed paint failure.

The results of the study established a better understanding of pavement marking deterioration and provided guideline on waterborne traffic paint failure projection for the department. Combined study year 1 and 2 data revealed that paint retroreflectivity failure occurs between 8 to 17 months after painting, depending on the AADT of the road. This improvement is a result of the change in paint formulation and application. The study also illustrates some other factors that could affect the life of paint, for example, winter activities. As this study progress, further data collection will be performed, and UDOT will use the results to improve its current pavement marking practices.

INTRODUCTION

The *Manual on Uniform Traffic Control Devices* (MUTCD) defines retroreflectivity as "a property of a surface that allows a large portion of the light coming from a point source to be returned directly back to a point near its origin." In other words, light from a vehicle's headlights is reflected back toward the headlights, near the driver's eyes. Good retroreflectivity is especially substantial for traffic safety because many roadways do not provide adequate overhead lighting to compensate for pavement markings exhibiting poor retroreflectivity. Good pavement markings will increase traffic flow, driver comfort, and traffic safety. MUTCD also states "Markings that must be visible at night shall be retroreflective unless ambient illumination assures that the markings are adequately visible. All markings on Interstate highways shall be retroreflective."

Utah Department of Transportation (UDOT) uses many types of pavement marking materials, like paint, epoxy, and tape. Five of six region paint crews are equipped with waterborne paint trucks. One region uses paint through a contract heavily. Since UDOT uses more than 90% of paint on the state highway system, it is necessary to conduct a study to determine the effective life of highway pavement marking made of durable waterborne paint.

Beginning in summer 2002, UDOT launched a 3-year study to determine when roads of low, medium, and high average annual daily traffic (AADT) should be repainted based on the retroreflectivity values of the paint. The threshold for retroreflectivity paint failure is a value of 100 millicandelas per square meter per lux (mcd/m^2/lx). This value is not required by law but is commonly used in practice.

OBJECTIVES

UDOT would like to know when the durable waterborne paint is expected to fail. Since time of paint failure is believed to depend on how much traffic a given road carries, several routes with different AADT were selected in this study. A statistical regression analysis was used to determine the predicted times of failure for paint on low, medium, and high AADT roads. With accurate paint failure information, UDOT can make more informed and cost effective decisions about deciding when to repaint state routes.

Also included in this report is an illustration of some other factors that could affect the life of paint. This perspective demonstrates that not only the volume of traffic could have effect on pavement marking system; other roadway activities and physical properties could affect the life of pavement marking.

HISTORY

The 1996 Emission Inventory Improvement Program documents from the Environmental Protection Agency (EPA) have indicated methods to be used to estimate emission. However, these documents were not binding guidance or rules. EPA, the states, and others retained the discretion to employ other approaches that meet the regulatory requirements in individual circumstance. Waterborne paints were created as an alternative to oil-based paints as an effort to lower the volatile organic compounds (VOC) emissions. Until September of 1999, EPA placed regulations on the amount of VOCs that could be present in traffic pavement markings. The limitation of VOCs in traffic marking paint is 150 g per liter (EPA 1999). UDOT converted to waterborne paint in 1998 before the EPA set the regulations.

Today, UDOT uses recently developed materials and technology to paint roads and monitor the effectiveness of the paint. The specifications and performance for Utah's waterborne paint continues to improve as the coating technologies advance. Once the paint has been laid down on the road, a mobile retroreflectometer has played a role in monitoring and evaluating paint retroreflectivity.

METHOD

Route Selection and Evaluation

The study began in the summer of 2002 with several selected state routes. These state routes are identified later in this report. Painting dates for each of the routes were recorded and kept on file. The retroreflectivity of each of the paint routes was evaluated under dry and daytime conditions using the Laserlux retroreflectometer. Retroreflectivity readings were taken periodically from the maintenance planning division. The study focused on white pavement marking only on both asphalt and concrete pavements with the following application rates: 18 to 20 wet mils for paint and 10 to 12 lbs for glass beads.

Pavement Marking Material

The specifications for the paint used on the highways in the study are shown in Table 1.

EQUIPMENT

Laserlux

In order to measure retroreflectivity safely and quickly, UDOT uses a van-mounted Laserlux mobile retroreflectometer as shown in Figure 1.

TABLE 1 Waterborne Pavement Marking Specifications

	Black	**White**	**Yellow**
Nonvolatile vehicle: Percent by weight vehicle	Minimum of 40. The nonvolatile portion of the vehicle is 100% acrylic crosslinking resin as determined by infrared spectral analysis. The acrylic emulsion is a 100% crosslinking emulsion.		
No-track Time	Not more than 5 min when tested according to ASTM D 711, at wet film of 15 mils.		
Volatile Organic Compounds Content	Maximum of 1.25 lbs/gal ASTM D 3960.		
Pigment: Percent by weight	62 ± 2 ASTM D 3723.		
Total Solids: Percent by weight	Minimum of 77. ASTM D 2205.		
Titanium Dioxide Content	N/A	Minimum of 1 lbs/gal rutile titanium dioxide.	Maximum of 0.2 lbs/gal rutile titanium dioxide.
Directional Reflectance	N/A	Minimum of 92 at wet film of 5 mils.	Minimum of 50 at wet film of 5 mils.
Contrast Ratio	N/A	Minimum of 92, at wet film of 5 mils.	Minimum of 90 at wet film of 5 mils.
Viscosity @ 75°F (KU)	80-95		
Density Lbs/gal	14.1 ± 0.2		
Scrub Resistance	N/A	Minimum of 800 cycles, at wet film of 5 mils.	

FIGURE 1 Laserlux mobile retroreflectometer mounted on a van.

The Laserlux conforms to the ASTM standard E1710, which prescribes what is known as the 30-meter geometry requirements for retroreflectometers. The 30-m geometry is important because it standardizes retroreflectivity measurements and represents "what a driver from an average U.S. automobile height would see during inclement weather conditions at night (Austin and Schultz 2002)." As the van drives down the road, the Laserlux scans a 1-m wide section of the pavement with a helium neon laser. As the pavement marking is found within the scanned section, the Laserlux identifies its peak retroreflectivity while taking measurements at a rate of 9 readings per second. These readings are displayed on a computer screen inside the van, and an overall average reading with variability is reported for a user-defined section of road. Hence, the retroreflectivity readings found in the results section of this report are actually average readings for the entire section of road, which may be up to several miles in length.

Test Sections

The test sections were selected in Region 1; routes from study year 1 and study year 2 are summarized in Tables 2 and 3, respectively. Some routes used in study year 1 were changed before initiating study year 2. The routes should remain the same throughout the remainder of the 5-year study. Their locations are shown on maps presented as Figures 2 and 3.

RESULTS AND DISCUSSION

The results of this study are divided into three discussions on high, medium, and low AADT routes in Utah. The divisions between high, medium, and low AADT are somewhat arbitrary and are summarized in Table 4.

TABLE 2 Study Year 1 (Year 2003) Routes

Route	Milepost	Region	Paint Applied	AADT
2003 Routes—Low AADT				
SR-315	0–1.7	1	7/1/02	1,810
SR-83	0–5	1	7/10/02	4,750
SR-126	14–21.5	1	6/25/02	5,600
SR-132	35–41	3	6/19/02	2,600
2003 Routes—Medium AADT				
SR-30	106–115	1	6/18/02	9,455
SR-235	3.1–4.9	1	7/1/02	8,500
SR-235	0–3.1	1	6/24/02	22,000
I-15	368–375	1	7/1/02	24,000
SR-108	1.5–3	1	6/3/02	18,065
US-89	338–345	1	7/11/02	30,300
2003 Routes—High AADT				
I-15	272–276	3	7/3/02	106,344

TABLE 3 Study Year 2 (Year 2004) Routes

Route	Milepost	Region	Paint Applied	AADT
2004 Routes—Low AADT				
SR-315	0–1.7	1	6/18/03	1,795
SR-83	0–5	1	6/17/03	4,909
SR-126	14–21.5	1	7/5/03	6,034
SR-30	106–115	1	6/21/03	5,095
SR-110	0–3.5	1	5/29/03	1,678
2004 Routes—Medium AADT				
SR-39	9–14	1	6/3/03	8,673
SR-91	3.1–4.9	1	5/19/03	15,380
I-15	368–375	1	7/31/03	24,982
SR-235	0–3.1	1	6/25/03	24,755
SR-235	3.1–4.9	1	6/25/03	9,814
2004 Routes—High AADT				
I-15	336-349	1	7/11/03	85,038

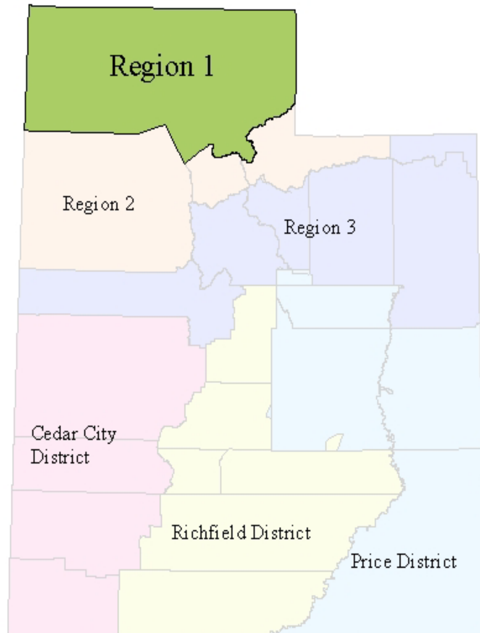

FIGURE 2 UDOT regional map.

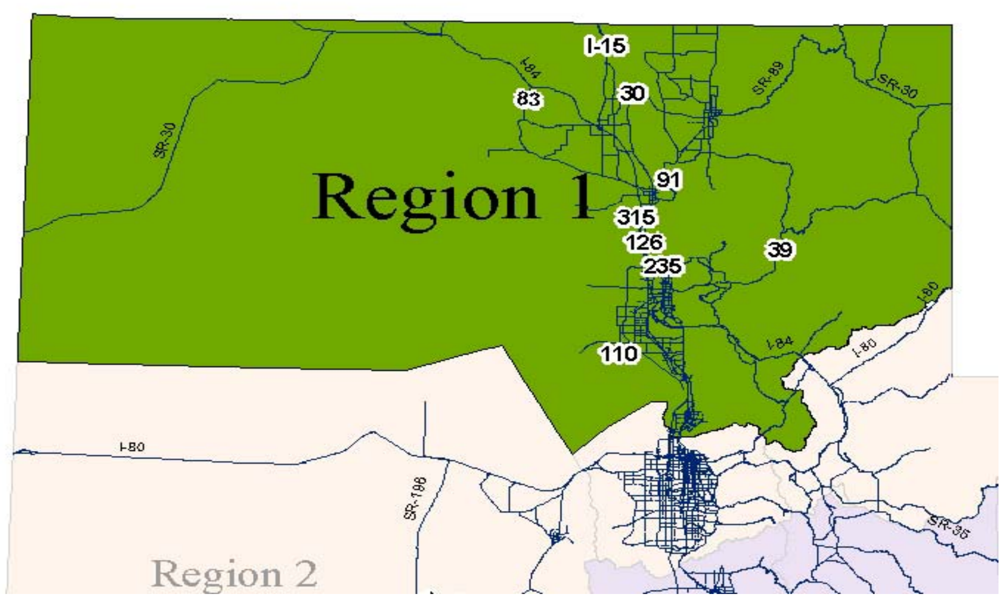

FIGURE 3 Close-up view of test section locations.

Each discussion contains a graph combines the first and second years of data that are used to derive a general forecast of paint failure based on AADT class. As a reminder, paint failure is assumed to occur at a retroreflectivity of 100 mcd/m^2/lx. Therefore, a reference datum of retroreflectivity equal to 100 is included on all graphs. Also, in order to judge the reliability of the results, 95% confidence bounds are placed around all regressions.

Following the three discussions, an empirical relationship between paint life and AADT for any road in Utah is presented. Also, an illustration is followed on other factors that could have impacts on pavement markings.

High AADT

The combined 2003–2004 high AADT regression, Figure 4, shows that paint retroreflectivity is expected to fail at 255 days, and as early as 165 days, from initial painting on high AADT routes. This time range means that maintenance paint crews could expect to paint high AADT routes every 8.5 months. An 8.5-month painting cycle is impractical because it will eventually encroach on wintertime, and painting is not to be done when the pavement temperatures are below 50°F. Therefore, maintenance crews should plan on painting high AADT routes once in the early spring and once in the late fall every year. In winter 2005, UDOT maintenance paint crews were able to paint some state routes, but this is an exception and not the rule.

Based on the pavement preservation program on high AADT routes, UDOT regional engineers are responsible to determine whether to use paint or more durable pavement markings such as tape, epoxy, or thermoplastics. These durable pavement markings could last up to 8 years, but they come with a significantly higher price tag. For example, waterborne paint costs about \$0.10 per foot, while popular pavement marking tapes costs anywhere from \$1.50 to \$2.10 per foot. A benefit of using these durable markings is that they are generally more retroreflective than waterborne paint throughout their useful life. New white tape, for example, generally has a retroreflectivity of 800 to 1000 mcd/m^2/lx, while UDOT's new white water-based paint with 10 lbs of glass beads per gallon of paint has a retroreflectivity of 300 to 400 mcd/m^2/lx. The question is: Is it worth the investment to increase retroreflectivity and durability that durable pavement markings provide?

It is important to note that in Figure 4 the lower bound of the 95% confidence interval crosses the retroreflectivity failure line at 165 days from the time of painting. Also, at 255 days the actual retroreflectivity could range from 50 to 150 mcd/m^2/lx. Both of these observations suggest that, with the existing data, we cannot accurately predict the time of retroreflectivity failure for high AADT roads in Utah. To mitigate this problem, more data points should be obtained from the 165-day mark until a short time after consistently failing retroreflectivity readings are collected.

TABLE 4 AADT Divisions Used in This Study

Low AADT	0–6,500
Medium AADT	6,501–25,000
High AADT	25,001–above

AADT = average annual daily traffic

Medium AADT

Figure 5 is the combined 2003–2004 regression with 95% confidence bounds for medium AADT routes in Utah. Again, the combined regression is used in this report to forecast paint failure in general. According to the graph, paint retroreflectivity fails at 455 days from painting and could fail as early as 335 days from painting. This result seems reasonable in that it concurs with the idea that paint lasts longer on lesser-traveled roads and the high AADT data that shows earlier failure. This observed relationship supports the belief that AADT has a primary influence on paint life.

The standard error about the regression at time of failure is ± 43 mcd/m^2/lx. However, the range of days when paint failure could occur is surprisingly larger on the medium AADT graph than on the high AADT graph even though there are many more sample points on the medium AADT graph. This occurrence results from the high AADT data being more spread out, whereas the medium AADT data are confined to the time period well before forecasted date of paint failure. While it is obviously beneficial to have many sample points, the spread of these points is equally important in order to forecast retroreflectivity failure accurately. Therefore, although it can be said that paint lasts longer on medium AADT roads than on high AADT roads, only an extrapolated estimate of the time to retroreflectivity failure can be determined for either traffic category.

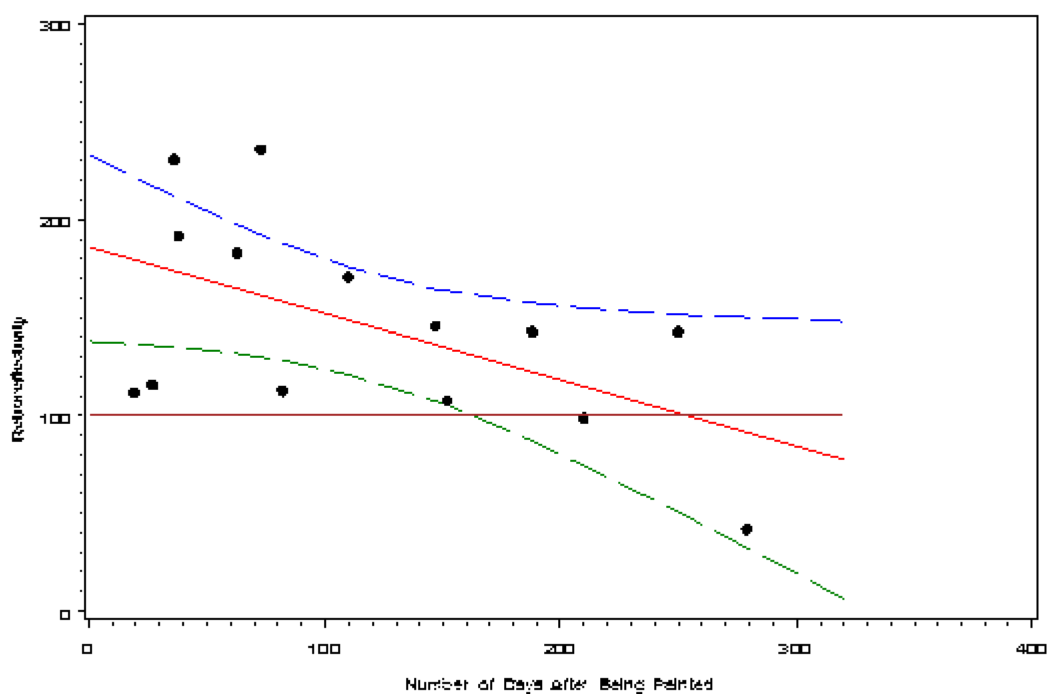

FIGURE 4 Retroreflectivity versus age of paint for high AADT routes, combined 2003–2004 data.

Low AADT

Figure 6 shows the combined regression for 2003 and 2004. Paint failure is shown to occur at 525 days and as early as 387 days from the initial painting. The standard error at time of failure is ± 50 $mcd/m^2/lx$. There is still much variability in the regression at time of failure, and that is because not enough sample points were taken around the time of failure. The standard error about the regression is as small as ± 15 $mcd/m^2/lx$ at one point in the regression where the sample points are equally distributed to the left and right. This point of division occurs around the 150-day mark. Therefore, if the sampling schedule were changed, a small standard error could be achieved around time of failure instead of earlier when it is not crucial.

Empirical Relationship

Based on the data collected over the first 2 years of the study, an empirical relationship between paint life and traffic is plotted on Figure 7. While only three points are shown on the graph, is based on the intersection of the regression lines with the retroreflectivity of 100 $mcd/m^2/lx$ in the combined 2003 and 2004 graphs of low, medium, and high AADT. Also, it is important to remember that each of the points in the combined low, medium, and high AADT graphs is actually an average of hundreds of measurements taken using the Laserlux. One data limitation is that each of those measurements has a certain degree of variability. Therefore, ordinates of the three plotted points in Figure 7 represent thousands of readings with certain degrees of variability attached to each. This variability limits the effectiveness of the empirical relationship developed from the graph. Yet, with all its simplicity, the regression still gives UDOT general guidance on how long their waterborne paint should last on roads in similar climates and with similar snowplowing practices as those in this study but with different AADT. Therefore, UDOT pavement marking committee is developing a pavement marking decision matrix for all types of pavements (Table 5).

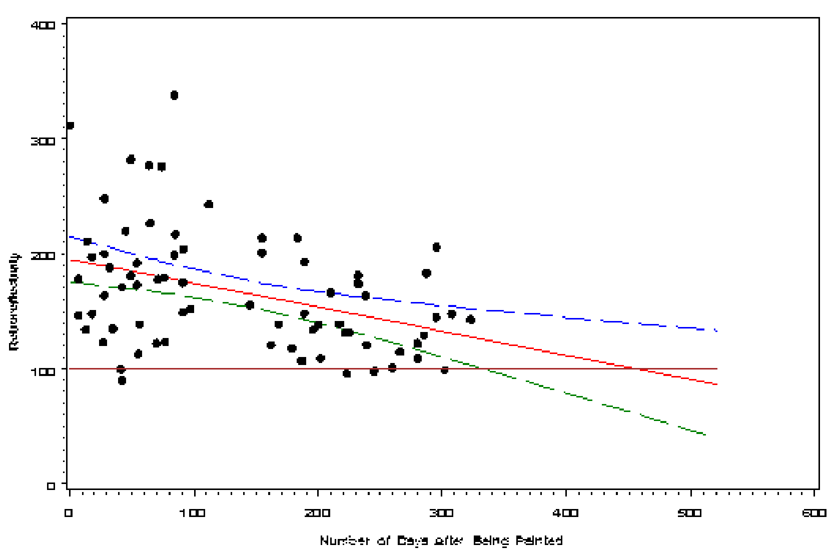

FIGURE 5 Retroreflectivity versus age of paint for medium AADT routes, combined 2003–2004 data.

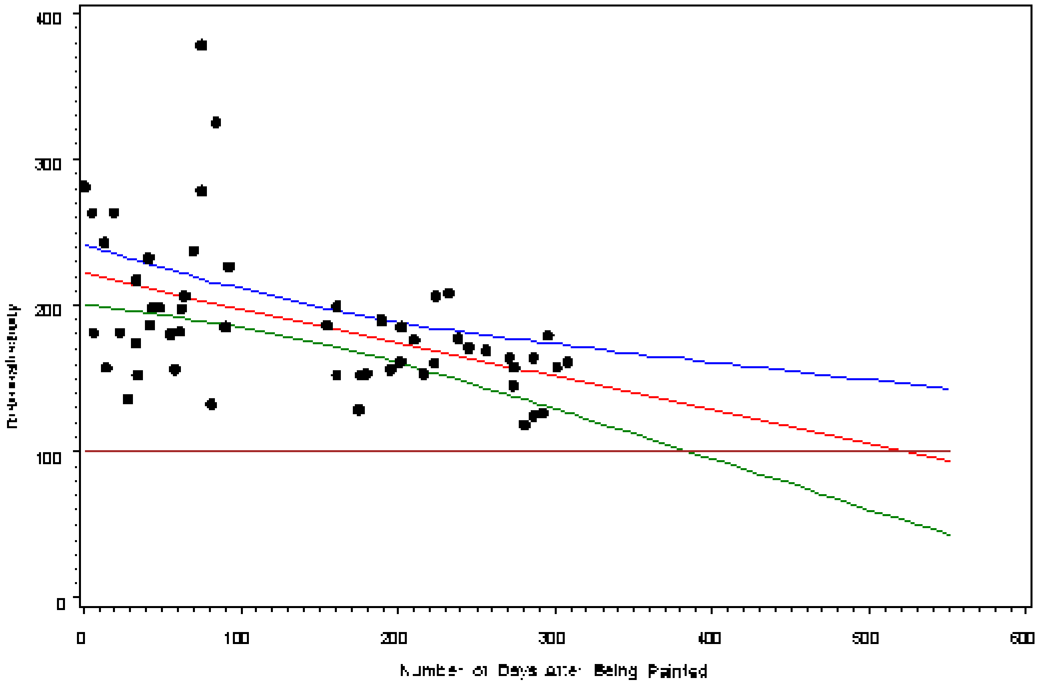

FIGURE 6 Retroreflectivity versus age of paint for low AADT routes, combined 2003–2004 data.

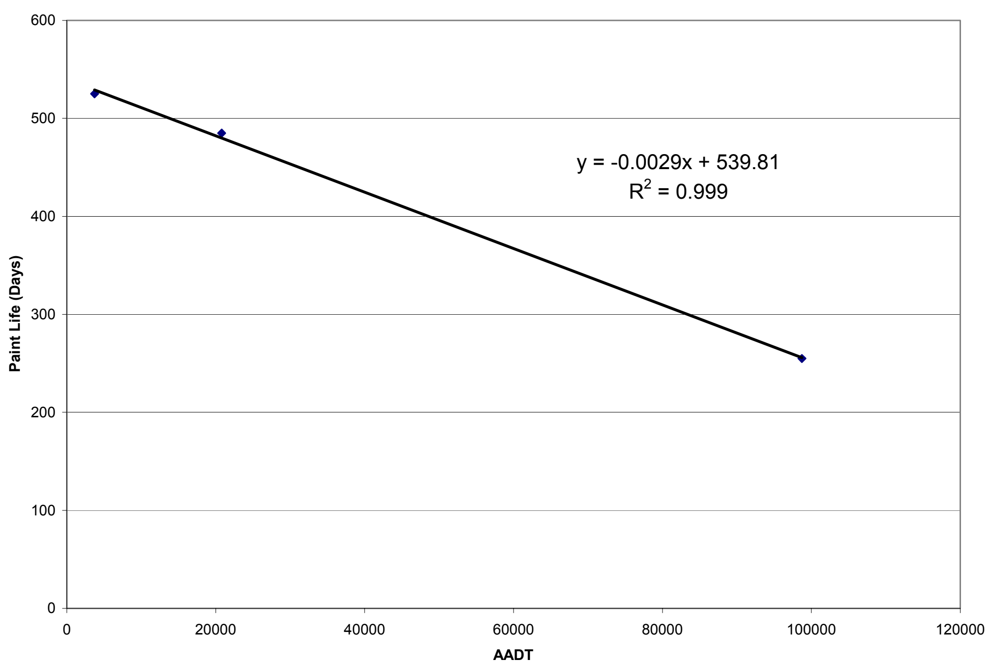

FIGURE 7 Empirical relationship between paint life and AADT.

Other Factors Affecting the Life of Pavement Markings

From the study, UDOT has learned that not only the traffic volume can reduce the durability of pavement marking materials; also many other roadway activities and physical properties can impact the life of pavement markings. The primary factors are snowplowing, curvature of a roadway, pavement type, and condition.

Snow and ice removal is a critical task for UDOT to maintain its highway system free of snow and ice during the winter months in order to provide motorists a safer driving condition. Therefore, UDOT takes snow and ice removal seriously. Snowplowing, sanding, and deslicking with grit are the common practices to clear the snow and ice until the highways reach to a desirable driving condition. On the other hand, the pavement marking suffers more damage as snowplowing activity increases. State Route (SR) 153, one of Utah scenic highways, is a good example to demonstrate this point. This 27-mi canyon pass is categorized in low AADT. The region paint crew painted the entire route in the summer of 2004 with waterborne paint. Figure 8 shows the new paint at milepost (MP) 13.1, which is about the summit of the Mountain. Eight months later in spring 2005, Figures 9 and 10 show the paint conditions at MP 3 and 13.1. MP 3 is at the mouth of the canyon; the paint was in excellent condition. This observation supports the belief that snowplowing has a certain influence on durability of pavement markings.

FIGURE 8 SR 153 MP 13.1 (summer 2004).

FIGURE 9 SR 153 MP 3 (spring 2005).

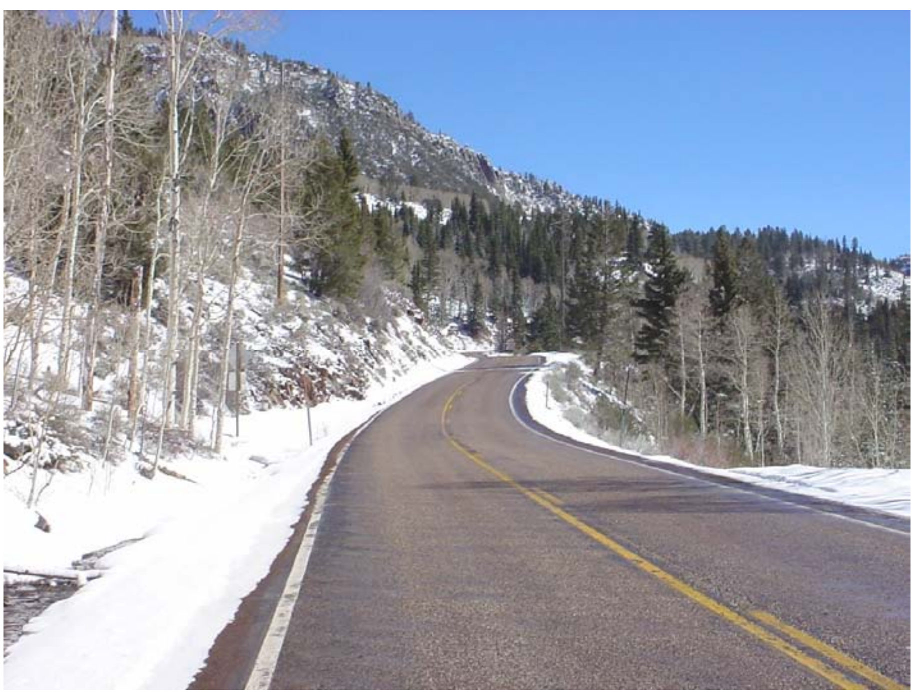

FIGURE 10 SR 153 MP 13.1 (spring 2005).

Physical properties of a roadway are also factors that make pavement markings deteriorate faster. For example, curves. Vehicles always have the tendency to crossover the pavement marking at the inside curves. In doing that, it artificially increases the volume of traffic on pavement markings. Figures 11 and 12 show the paint conditions on SR 153 at MP 13 and 13.1.

CONCLUSION

The purpose of this study is for UDOT to understand when waterborne paint is expected to fail on state roads of differing traffic. The results from study show that paint should fail between 8 and 17 months from the initial painting depending on the traffic volume of the road. UDOT has used this information to develop a pavement marking decision matrix shown in Table 5. This matrix is a general pavement marking decision guidelines and recommendations, UDOT regional engineers are responsible to determine what types of pavement marking materials to use on projects based on AADT, pavement type, pavement life, climate, etc. As this study progress, further data collection will be performed, and results will benefit UDOT to make better decisions to improve its current practices.

FIGURE 11 SR 153 MP 13 (spring 2005).

FIGURE 12 SR 153 MP 13.1 (spring 2005).

TABLE 5 Pavement Marking Decision Matrix

Pavement Type	Condition	AADT per Lane		
		Low <15,000	**Medium 15,000–50,000**	**High >50,000**
Asphalt	New (pavement life > 5 years)	Waterborne	Tape Waterborne Epoxy	Tape Polyurea Epoxy
	Fair (2 < pavement life < 5 years)	Waterborne	Waterborne Epoxy	Tape Polyurea Waterborne Epoxy
	Poor (pavement life < 2 years)	Waterborne	Waterborne	Waterborne
Concrete	New (pavement life > 5 years)	Waterborne	Tape Waterborne Epoxy	Tape (grooved) Polyurea Epoxy
	Fair (2 < pavement life < 5 years)	Waterborne	Waterborne	Polyurea Waterborne Epoxy
	Poor (pavement life < 2 years)	Waterborne	Waterborne	Waterborne
Chip seal or overlays	Less than 1 year	Waterborne	Waterborne	Waterborne
	More than 1 year	Waterborne	Polyurea Waterborne Epoxy	Polyurea Waterborne Epoxy

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REFERENCES

ATSSA/ITE/AASHTO. *Manual on Uniform Traffic Control Devices Millennium Edition.* FHWA, U.S. Department of Transportation, 2001

Austin, R., and R. Schultz. *Guide to Retroreflection Safety Principles and Retroreflective Measurements*, Gamma Scientific, San Diego, California, 2002.

Environmental Protection Agency. *Pavement Markings*, Vol. III, Chapter 14, 1997.

Environmental Protection Agency. Part 59 of Title 40 of the Code of Federal Regulations, 1999. http://www.epa.gov/ttn/oarpg/t1/fr_notices/rule812.pdf. Accessed Jan. 11, 2005.

Garney, J. *Jeff Garney's Master Project.* Provo, Utah, 2005.

Utah Department of Transportation Program Development Division. *Traffic on Utah's Highways 2002*, UDOT, Salt Lake City, 2002.

APPENDIX

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The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. On the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. William A. Wulf is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, on its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both the Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. William A. Wulf are chair and vice chair, respectively, of the National Research Council.

The **Transportation Research Board** is a division of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's mission is to promote innovation and progress in transportation through research. In an objective and interdisciplinary setting, the Board facilitates the sharing of information on transportation practice and policy by researchers and practitioners; stimulates research and offers research management services that promote technical excellence; provides expert advice on transportation policy and programs; and disseminates research results broadly and encourages their implementation. The Board's varied activities annually engage more than 5,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.
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