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Maintenance and Operations of Transportation Facilities

2005 Strategic Vision

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Preface

This publication contains an update of a paper prepared by members of the Transportation Research Board (TRB) Maintenance and Operations Management Committee in 1999 as part of TRB's Millennium Papers (www4.trb.org/trb/onlinepubs.nsf/web/millenium_papers) to respond to rapid changes in the state of the art and practice in the field of maintenance and to present their perspectives on future directions in light of these changes. The document provides a thoughtful and perceptive review prepared by experts fully engaged in advancing the way the traveling public is served and provides a comprehensive view of transportation maintenance. As a TRB committee initiative, of course, the document gives research its due attention.

Maintenance and Operations of Transportation Facilities

2005 Strategic Vision

The importance of maintenance is increasingly recognized as we continue in the 21st century. With the Interstate highway system essentially in place, the focus of transportation programs is shifting from capital investment to maintenance and operation. Senior executives, legislators, and the public consider maintenance key to not only protecting the nation's multibillion-dollar highway investment but also continuing to provide a safe, efficient transportation system. Funding for new highways on the scale of the Interstate program is not likely to be allocated again in the foreseeable future. The challenge for maintenance managers is to achieve maximum performance from the existing system, which will continue to be paramount for the foreseeable future.

In this document, the members of TRB Maintenance and Operations Management Committee (AHD10) identify the major trends that affect maintenance; cite current and emerging innovations in management systems, technology, and intelligent transportation systems (ITS); and examine the key maintenance challenges of this century. The authors envision that careful planning combined with focused maintenance research and implementation will help the nation overcome the highway transportation and environmental challenges of the coming decades.

TRENDS THAT AFFECT MAINTENANCE

Maintenance professionals face important challenges: to provide efficient transportation with an aging infrastructure, to meet growing public and legislative demands for accountability, and to manage the rapid pace of change. With these challenges come exciting opportunities. Today maintenance is more visible than ever before, and changes in maintenance management are moving faster than they have been since the 1960s. In state departments of transportation (DOTs) across the nation, many exciting new developments are under way to improve business practices, transform organizations, and leverage new technologies. The major trends that affect maintenance include the following:

- Infrastructure growth is slowing, so the maintenance, preservation, and rehabilitation of existing infrastructure are becoming increasingly more important. As public funding shifts from construction to maintenance, maintenance organizations become more accountable to administrators, politicians, and the public for a safe, convenient, and accessible transportation system. This shift in emphasis brings new governance and institutional issues.
- The nation's aging infrastructure is challenging maintenance managers, who must respond with more effective business practices. Innovations in management systems, resources, materials, technology, equipment, and work methods help improve maintenance effectiveness and efficiency at the network and activity levels.
- Technology is changing the kinds of information and infrastructures that must be maintained. Advanced technology is increasingly being incorporated into the transportation infrastructure, and as a result, new maintenance procedures and a very different set of skills for maintenance managers as well as maintenance workers are being required.

- Technology is affecting how maintenance is performed. Information technology, especially advances in integrated information systems, removes institutional and organizational barriers throughout the enterprise. Other tremendous advances are taking place in areas such as data collection, diagnostics, analytical techniques, material science, and maintenance equipment.
- The political climate that calls for smaller government is making its mark on the institutional and cultural aspects of maintenance organizations. Fewer maintenance staff in state DOTs means increased use of private contractors and alliances with local agencies to provide the resources to enhance overall transportation services to the customer.
- State DOTs are implementing private-sector best practices in customer service and performance management. Public perception and expectations for better service change the way maintenance managers define and respond to customer needs. Demand for government accountability brings about new ways to measure maintenance performance. Emerging trends include outcome-based planning, budgeting, and measuring results.
- Recruiting and retaining a skilled DOT work force are becoming more difficult. The private sector tends to pay higher salaries for technology jobs, thus attracting many potential recruits away from highway maintenance careers.
- Environmental concerns continue to have a significant effect on maintenance. New regulations are anticipated, and the trend is toward stronger enforcement of existing regulations.

Slowdown in Highway Construction and an Aging Infrastructure

Throughout most of the 20th century, federal, state, and local agencies pursued a mission to build a national and Interstate highway network that would support burgeoning commerce and development in the United States. Congress saw the federal role as financing and supporting construction and as such made almost no provisions for maintaining the highway system. The responsibility for maintenance and operations was left to the state and local agencies.

Without an emphasis on maintenance, highway and bridge infrastructure aged more rapidly than it could be reconstructed or rehabilitated. Currently, new attitudes toward maintenance prevail as understanding and awareness grow. Preservation of assets and mobility are high-priority challenges for a highway system that is essentially in place.

With the Interstate system construction essentially completed, federal involvement in maintenance has been increasing. The federal government instituted a program of reconstruction, rehabilitation, resurfacing and restoration and slowly expanded its role in funding maintenance.

From the early 1990s, federal legislation placed increased emphasis on preservation of the system, environmental stewardship, fostering of greater use of nonhighway modes of transportation, intermodal connections, operational improvement, and advanced technology to promote a more efficient surface transportation system. The Intermodal Surface Transportation Efficiency Act of 1991 established the Interstate Maintenance Program and called on states to implement pavement, bridge, and other management systems as tools to preserve the current systems and maximize its efficiency. Managed preservation of the highway infrastructure had moved to a position of nationwide importance.

In the late 1990s, federal legislation renewed the emphasis on construction, as legislators earmarked numerous high-priority demonstration projects. However, with formidable funding and environmental barriers to new construction, the importance of maintenance and operations solutions to transportation problems remains a key issue to this day.

The emphasis on maintaining and operating our existing system in lieu of new

construction will continue for the foreseeable future. Accountability for meeting the nation's transportation needs will rest with maintenance. The federal role will continue to shift from construction to maintenance, and states will be given more latitude in how their federal maintenance dollars are spent.

System operations will become even more important as traffic volumes continue to increase faster than construction of additional capacity. This will require the maintenance manager to become more involved with operating the system effectively and coordinating maintenance with traffic operations.

Technology-Based Infrastructure

The application of technology to meeting transportation needs has become an integral part of transportation infrastructure. The ITS consists of some 30 different user services that involve various systems, including the advanced traffic management system and the advanced traveler information system.

These technologies and others, such as roadway weather information systems (RWIS) (Figure 1), the Global Positioning System (GPS), and geographic information systems (GIS), are becoming widely used and beneficial to both motorists and maintenance organizations. For motorists, they provide the tools to maximize system efficiency and safety as well as traveler advisories. For maintenance organizations, they provide real-time information, allowing rapid response to emergencies and traffic incidents.

FIGURE 1 An RWIS.

Although these technologies provide benefits in operating the infrastructure, they also create a maintenance need very different from that of the past. Managing these technology-based assets requires skilled technicians and a proper preventive maintenance program to achieve maximum operability and optimum cost-effectiveness. Maintenance personnel in the future will need increased technical skills in electronics, robotics, computerized systems, virtual reality, expert diagnostics, and related areas to maintain our technology-based infrastructure.

We are just beginning to see the use of advanced technologies in highway infrastructure operations. Radically new technologies will be used throughout the highway system during the 21st century. Whether the actual maintenance will be done with in-house forces, contracted out, or left to technology suppliers, the ultimate responsibility for maintenance will rest with the maintenance manager.

Technology for Better Maintenance Management

Technology is changing the business of maintenance management. Tremendous advances in applying technology for better management, physical technologies as well as information technology are under way. Significant breakthroughs are taking place in many areas, as illustrated by the following examples:

- Technologies such as RWIS provide real-time data about pavement surface and weather conditions and allow more timely deployment of winter maintenance crews and use of chemicals in proactive snow and ice control operations.
- Development of advanced maintenance concept vehicles (Figure 2) under the sponsorship of Minnesota, Michigan, Iowa, Pennsylvania, and Wisconsin has the potential to enhance productivity through equipment design.
- South Dakota's spray-applied patching machine and California's experimental crack-

FIGURE 2 Advanced maintenance concept vehicle.

sealing machine have the potential to improve efficiency, minimize lane-closure time, and increase safety for operators and motorists.

- Advances in diagnosing infrastructure performance, such as pavement cracking and sign reflectivity, help track asset conditions and determine maintenance needs.
- GIS and digital databases of roadway assets allow managers to view asset characteristics, assess field conditions, and deploy resources to solve maintenance problems without time-consuming field trips.
- In the future, maintenance vehicles and equipment will include GPS guidance systems, robotics, improved hydraulics, and advanced electronics such as digital voice and data communication systems.

New technologies that are not known at this time will be applied to highway maintenance. It is anticipated that all of these will lead to better decisions by maintenance managers and more productivity in maintenance operations.

In the area of information technology, advances in software, hardware, and telecommunications (including the Internet) will increase the feasibility of data collection systems, enterprise databases, and integrated decision support systems for maintenance management. These trends were evident, as reported in *NCHRP Report 363: Role of Highway Maintenance in Integrated Management Systems* (*1*), and have been field tested in snow and ice control operations (*2*).

Integrated maintenance management systems (IMMS) that encompass bridge, pavement, equipment, financial, and materials management are within sight. Funding and organizational barriers that previously inhibited IMMS development are beginning to be addressed as technologies becomes more affordable and the benefits across the enterprise are recognized.

The Internet has become a powerful communications tool between DOTs and their customers. Every state DOT has a home page on the Internet. Through public access of their home page, states provide important information on such topics as road conditions, construction work locations, budgets, and program funding to their customers. Communication with customers will continue to expand for the foreseeable future. Information kiosks and WiFi Internet access installed at some Interstate rest areas give customers real-time visual display of road and weather conditions, including current roadway construction. Motorists are able to plan and modify their travel along the safest, least congested routes.

Growth in Maintenance Contracting and in Public and Private Partnerships

Contracting and maintenance outsourcing are growing trends worldwide. Although the rate of growth is slower in the United States than abroad, the use of private contracting is increasing.

Nearly all states contract out a portion of their maintenance program. Activity-based contracting is the most prevalent form of maintenance contracting and will remain so for the foreseeable future. Florida, Texas, Massachusetts, and Virginia, to name a few, have taken some of the most innovative approaches to contracting maintenance. Florida has implemented several geography-based contracts in which the contractor is responsible for providing end result performance on almost all maintenance activities on designated portions of the system. On specific sections of its Interstate system, Virginia has implemented a performance-contracting approach whereby the contractor is responsible for achieving specified system performance and outcomes.

To maximize the use of resources, state DOTs also are reevaluating their relationships

with other government agencies. For example, Pennsylvania has implemented a program called Agility to form temporary maintenance enterprises with local governments and other state agencies. This program brings together state and local agencies to combine their strengths toward a goal of providing motorists with a seamless transportation system.

Although maintenance contracting will increase, states probably will not contract out their entire maintenance programs. They will retain a core staff that can respond rapidly to snowstorms, floods, hurricanes, and other disasters. The Florida DOT director of highway operations, who experienced eight major hurricanes in the past 2 years, indicated that "without the asset management contracting industry, it would have been difficult to perform as well as we did." Knowing how large a core staff to retain and how much should be contracted will become a challenge for the maintenance managers.

Increased emphasis will be placed on performance-based end-result specifications rather than method and material specifications. New contracting models will emerge to fit each agency's local culture, labor practices, and political climate.

New Business Practices in Performance Management and Customer Service

The public debate over government accountability provides an impetus for maintenance organizations to implement better business practices. New management approaches for maintenance planning, budgeting, and performance measurement are tied to customer needs and expectations. Similarly, maintenance organizations are defining outcomes and performance in terms that are easily understood by the general public and thus improve communication between customers, legislatures, and stakeholders.

Performance measurement utilizing a maintenance quality assurance program is becoming a key element in the overall performance management approach. The Florida DOT has been measuring maintenance performance with its maintenance rating program (MRP) for nearly 20 years. The Florida DOT is required by law to maintain its highway systems at a specified level of performance. The MRP is increasing both understanding and confidence with the Florida legislature.

Minnesota is improving customer service in all aspects of its highway management, including maintenance. The state-set maintenance goals and programs require regular assessments of customer satisfaction and desires. Washington State's Maintenance Accountability Process (MAP) is another example. The MAP allows the Washington DOT to communicate maintenance outcomes in clear, nontechnical terms to the public, legislators, and budget analysts. When they understand what their maintenance dollars are buying, legislators are more likely to fund maintenance needs.

Other states are implementing overall performance measures with a number of different systems and for a variety of reasons. Without some form of performance measures there is no way to determine the effectiveness of the maintenance provided or how it can be communicated to the customer.

Agencies seek to measure not only outputs and outcomes but also value added in terms of avoidable user costs (e.g., travel time, accidents, vehicle operation), avoidable taxpayer costs (expressed in terms of savings over a life cycle), and reductions in externalities such as air, noise, and water pollution.

Other private-sector business practices that are being implemented by transportation agencies include continuous quality improvement, business process reengineering, and

technology business planning. The real success is that maintenance managers are taking a more businesslike approach to maintenance. The maintenance manager of the future may be less technically trained and more business-oriented than the present maintenance managers.

Environmentally Sound Maintenance Work Practices

Maintenance must consider environmental regulations and impacts that are quite different from those associated with new construction. Examples of some maintenance practices that require special consideration include

- Containing structures when removing lead paint;
- Implementing National Pollutant Discharge Elimination System regulations;
- Discarding cut vegetation and road debris;
- Avoiding contamination of wells from road salt and street sweeping;
- Implementing proactive, environmentally sensitive snow and ice operations;
- Disposing of drainage system waste; and
- Cleaning up and disposing of accidents and hazardous material spills.

These environmental regulations affect efficiency, work methods, and budgets. Because maintenance is growing in complexity and importance, the need to adopt best management practices for environmental issues related to infrastructure maintenance will increase. Together, the creation of the TRB Environmental Maintenance Task Force, the subsequent establishment of the TRB Environmental Maintenance Subcommittee, and the publication of the *NCHRP Synthesis 272: Best Management Practices for Environmental Issues Related to Highway and Street Maintenance* (*3*) and NCHRP Project 25-25 (04), *Final Report: Environmental Stewardship Practices, Procedures, and Policies for Highway Construction and Maintenance* (*4*) are explicit acknowledgments of this trend and its increasing importance. New and significant growth in environmental laws is not expected. However, more stringent enforcement of current regulations will significantly affect future maintenance programs. The NCHRP Project 6-16, Guidelines for the Selection of Snow and Ice Control Materials to Mitigate Environmental Impacts, is currently developing guidelines and testing procedures to assist field maintenance personnel in becoming better environmental stewards.

FUTURE CHALLENGES AND GETTING PREPARED

The importance of maintenance is growing and its character is changing. Major factors influencing these changes include

- Increased accountability of maintenance professionals for stewardship of the nation's multibillion-dollar transportation investment;
- Implementation of emerging technologies;
- Implementation of customer-oriented management systems and business practices;
- Realignment of institutional relationships between local, state, and federal governments; and
- Increasing dependence on public and private partnerships to implement maintenance programs.

Attitudes toward the value of routine maintenance activities are evolving with the realization that many are necessary even though the best construction techniques were used when the facilities were built. Most of these are safety related, such as the repair and replacement of signs, pavement markings, storm cleanup, debris sweeping, incident management and cleanup, litter removal, snowplowing, bridge inspection, rest area operations, and drainage structure cleaning and repair. These functions are critical to the safe and efficient operation of the highway system and its components and must be included in maintenance planning.

Tremendous change has been afoot throughout the entire highway industry. Without question, maintenance professionals will have to respond to ever changing needs. In the future, agencies that stand out as high performers and industry leaders will be those that recognize the changing role of maintenance, embrace it, and take proactive measures to ensure that they are ready to meet future challenges.

Smart Implementation of Emerging Technologies

It is impractical to think that every state can or even should implement every new technology. Many new technologies have been tried without success. Experience can point to valiant efforts to implement new technology that, in reality, did not fit the agency's operating environment. Although attempted with the best intentions, the initiatives did not achieve the intended objectives.

As rapidly as technologies are advancing, agencies can easily be lured into believing that technology offers ultimate solutions to maintenance problems. Likewise, a one-size-fits-all mentality is not prudent with respect to emerging technologies. What works well in one state might not be appropriate in another.

Notwithstanding the risks associated with its implementation, technology is vital to the future of maintaining and operating the transportation system efficiently. Many new technologies will increase productivity, improve worker safety, prolong the life of assets, allow better management of the infrastructure, and enable top-quality customer service.

Meeting the challenge will require strategic and tactical actions at both national and state levels. On the national level, research is the key to identifying, designing, developing, and testing new technologies. New thinking will be required to encourage the development of new products and methods. There is little incentive for an industry to develop a new product or methods as there is little guarantee that the industry will be able to recover its development costs. It is conceivable that industry and government may have to develop new products and methods jointly and then be willing to share these products and methods with the entire industry.

Maintenance has never been the focus of significant basic and applied research as has road design, construction, and traffic flow. Efforts to understand infrastructure properties and performance are frequently related to areas of highway expertise such as geometric and structural design; selection of materials properties; provision of sufficient capacity, intersections, and interchanges; location and specification of safety devices and appurtenances; and location and characteristics of signs and signals. Comparatively little research has been devoted to the benefits of remedial or preventive maintenance, either in theoretical or empirical terms. While the Strategic Highway Research Program included some specific field studies and equipment enhancements for maintenance, several areas of basic maintenance management need more comprehensive investigation:

- A better understanding of the long-term (i.e., life-cycle) impacts of remedial and preventive maintenance, respectively on road, bridge and ancillary component performance, costs, and customer perceptions of quality;
- Cost–benefit comparisons of competing maintenance and preservation treatments and capital-maintenance trade-offs (i.e., when does maintenance become uneconomical, creating the need for a capital repair or rehabilitation project?);
- More effective ways to support and sustain preventive maintenance strategies;
- Fundamental relationships between maintenance levels of service (such as those implemented in Florida's MRP and Washington's MAP programs discussed earlier and in several other states more recently), and budget and labor requirements; and
- Best practices in specifying maintenance and operations performance, as used in contracting for these services.

The AASHTO Subcommittee on Maintenance in cooperation with FHWA is expected to continue looking for better methods to improve overall maintenance and operations management. This effort can be done through workshops, at the subcommittee annual meeting (Figure 3), in conjunction with various TRB committees and with approval by the AASHTO Subcommittee on Research of a program of maintenance research projects. The initiatives may be conducted through NCHRP and with the cooperation of FHWA. The initiation and continuation of these kinds of initiatives along with presentation of the results at national and regional forums can be critical to long-term improvement in maintenance management.

At the state level, each state must implement technologies prudently, in recognition that not all technologies work equally well in all states. Each state can implement strategic planning procedures that will provide the necessary guidance for its maintenance programs. With well-defined strategic goals and objectives, each state can effectively assess how it will use technology to meet its maintenance and operations needs.

Developing a Skilled Work Force of Maintenance Managers and Technicians

The U.S. military is one of the most technologically advanced organizations in the world, yet military leaders recognize and regularly proclaim that the technology would be useless without the skilled personnel to support it. That same premise applies to highway maintenance. Because of the rapid advances in technology, both built into the infrastructure and used to maintain it, a highly skilled work force is vital.

The maintenance work force is becoming more professional, and specialized maintenance training has been added in many states. Some states have graduate engineers managing most of their county maintenance organizations, and graduate engineers are being involved in the maintenance area earlier in their careers. Universities are introducing maintenance topics into existing curriculum by adding maintenance considerations to traditional design, construction, materials, and engineering management courses, and by introducing life-cycle design. Recognizing the importance of having a skilled organization, states have implemented maintenance training programs for personnel at all levels of maintenance. States are offering training programs of varying scope and focus. As new technologies are introduced, training of maintenance personnel will take on added importance. The highway industry already has a model for technical training with its National Institute for Certification in Engineering Technologies program (www.nicet.org) for construction personnel. A similar industry-wide approach to certifying maintenance technicians would help develop a

FIGURE 3 AASHTO subcommittee annual meeting.

more skilled and professional maintenance workforce.

State DOTs are being challenged to recruit and retain a highly competent staff. Young people entering the work force are attracted to high-technology jobs that offer exciting opportunities and better pay. Maintenance organizations in both the public and private sectors will need to continue developing innovative programs for training, advancement, and monetary reward.

Implementing Performance-Based Management Systems for Customer Service

Maintenance organizations will no longer be allowed to measure performance solely in terms of budget compliance or units of work performed. The public demands accountability for results and wants assurance that its highway tax dollars are being invested wisely. Work has been done in many states to develop performance measures for maintenance that include the quality of results in addition to the quantity of work accomplished. The new paradigm for maintenance management is expected incorporate performance management and customer service at all organizational levels. Performance management elements may include

- Obtaining customer input on maintenance program objectives, levels of service, and investment options;
- Incorporating life-cycle cost analysis into maintenance investment strategies;
- Developing performance-based budgets and programs that are geared toward achieving specific levels of services and outcomes;
- Infusing customer-oriented decision making in the day-to-day assignment of maintenance resources and providing a uniform level of service on the highway system;
- Measuring maintenance program outcomes in non-technical terms, so results can be clearly communicated to the public, budget analysts, and legislators; and
- Integrating information systems to achieve consistent, nonduplicated stewardship of asset data across the enterprise.

Instilling a new culture that is focused on customer service will be essential. Maintenance professionals will need effective management skills that balance technical, business, and interpersonal relations.

Developing Effective Public and Private Partnerships, and Contracting Procedures

As maintenance contracting continues to grow, maintenance managers will find innovative ways of contracting and creating public and private partnerships with appropriate levels of risk sharing. The highway industry is moving toward performance specifications for construction. Similar performance specifications for maintenance are expected to be developed and implemented. Understandably, this new business approach will cause uncertainty in the contracting industry. States are expected to work with local contracting associations and contractors to develop specifications and contracting methods that will benefit the public. The methods and contracting procedures will differ from state to state. By involving the local contracting industry, each state will find practical, cost-effective approaches to maintenance contracting.

Maintenance contracting does not lend itself to traditional highway construction contracting methods. Plans and specifications for maintenance functions cannot always be prescribed or developed by using the construction model. Maintenance must be responsive to daily conditions and public needs, which are difficult to express in contractual language. Low-bid maintenance contracting may have long-term detrimental effects on responsiveness, as contractors are forced to bid low and then strictly adhere to broadly worded specifications. Maintenance managers will need to evaluate their objectives for contracting and then carefully structure the programs so that contracting will achieve quality, responsiveness, and cost effectiveness. Individual maintenance managers will need to determine the proper balance between contracted maintenance and in-house maintenance, while providing consistent levels of service for the highway system. The correct balance between the two will be different for every state.

Breaking Down Institutional Barriers

Because maintenance and operations encompass such a diverse set of activities, responsibilities usually are dispersed throughout a highway organization. The responsibility for pavement management, bridge management, or asset management systems, for example, may be in the maintenance, planning, design, or materials units. The organizational structure of a specific DOT cannot be predetermined or universally prescribed. The most appropriate structure for a given situation will depend on many factors, which include culture, operating and political environment, and staff competency. However, as maintenance becomes the focus of highway agencies more and more, top executives will need to take steps to make certain organizational barriers do not negatively impact the agency's ability to deliver a high performance maintenance program.

SUMMARY

The character of maintenance is changing rapidly as we continue in the 21st century, and the pace of change will continue to accelerate. Except for incremental progress in equipment and materials, the first 60 years of highway maintenance changed little. In the mid-1970s, technology began to advance, and it continues to do so very quickly. The changes under way involve

business attitudes and basic cultural values of the organization. Overall, change has been beneficial. Maintenance organizations are more professional, more productive, and provide higher quality and uniformity of service than ever before. The results are safer highways and more cost-effective maintenance.

We cannot know for sure what maintenance will be like in 20 years. We can only learn from the past and be aware of trends that are developing today. The only thing for certain is maintenance will be very different. The political climate is trending toward smaller government, while both car and truck traffic volumes are increasing on a highway system that is rapidly aging. To be successful stewards of the customers' tax dollars, the maintenance community will need to anticipate and prepare for the future. Strategic initiatives are expected to include

- Increase awareness by citizens and legislators about the importance of maintenance in preserving our assets while providing a safe and efficient transportation system.
- Within the maintenance community, promote a culture of continuous improvement with a view that technology, business practices, and management techniques should change continually for the benefit of customers.
- Investigate the possibility of government and industry jointly developing new products or methods, either or both contributing technical expertise and monetary resources.
- Accelerate technical research in maintenance methods, equipment, materials, diagnostic procedures, and asset performance to harness technology and capacity and to implement the most efficient maintenance practices possible.
- Explore the use of private contractors and alliances with local agencies to provide the resources to enhance overall transportation services to the customer.
- Work toward national standards for professionalism and competency to raise the education, training, pay, and recognition of maintenance professionals in an effort to provide the skilled work force that will be needed for this new environment in the 21st century.

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