Leadership's Guide to Emerging Highway Preservation, Maintenance, and Renewal Practices

Leadership's Guide Contents

Leadership's Guide Orientation

This guide seeks to stimulate interest among leaders of transportation agencies in fostering emerging and innovative practices as they relate to the preservation, maintenance, and renewal (PMR) of highways and in providing assistance in this effort. The advancements in high-performance materials, tools, and technologies emerging from research, industry, and leading-edge public-sector practitioners offer exciting opportunities for significant improvements in the typically slow-to-change area of highway PMR.

This guide is prepared under NCHRP Project 20-83(03)A, "Long-Range Strategic Issues Affecting Preservation, Maintenance, and Renewal of Highway Infrastructure." This project addresses long-range strategic issues (30 to 50 years into the future) that will likely affect transportation organizations. This project is one of seven studies; the other six topics in the series, published as *NCHRP Report 750: Strategic Issues Facing Transportation*, Volumes 1 through 6, are as follows:

- Volume 1: Scenario Planning for Freight Transportation Infrastructure Investment (Caplice and Phadnis, 2013)
- Volume 2: Climate Change, Extreme Weather Events, and the Highway System: Practitioner's Guide and Research Report (Meyer et al., 2014)
- Volume 3: Expediting Future Technologies for Enhancing Transportation System Performance (Popper et al., 2013)
- Volume 4: Sustainability as an Organizing Principle for Transportation Agencies (Booz Allen Hamilton, 2014)
- Volume 5: Preparing State Transportation Agencies for an Uncertain Energy Future (Sorenson et al., 2014)
- Volume 6: The Effects of Socio-Demographics on Future Travel Demand (Zmud et al., 2014)

The audience focus for this guide is agency leadership, which includes the Chief Executive Officer (CEO) and those who directly report to the CEO and affect the direction, decisions, and collective day-to-day activities of the organization—often collectively referred to as "senior management." A companion guide, prepared under this project, focuses on the practitioner as the primary audience.

Leaders recognize that a key component of leadership is anticipating and helping to shape the future while guiding their organization through strategic deliberations and decision making. They also recognize that predicting the long-term future, extending outward 30 to 50 years, is a daunting task replete with uncertainty. With that in mind, this guide does not offer a long-term blueprint to guide future PMR practices in the decades ahead. The guide addresses the advantages of embracing emerging PMR practices to maximize value-for-money over the long run, offer examples of highly promising innovative practices, and suggest specific ways for the leaders to self-assess their agencies' capability in fostering innovative practices in general (not only those related to PMR). The two key assumptions underlying this guide's approach to fostering PMR innovative practices are as follows:

- A robust and increasingly resilient and adaptive network of streets and highways, including pavements, bridges, tunnels, drainage systems, and other ancillary components of highway infrastructure, will continue to be needed over the next half-century under any plausible set of circumstances.

- The ways in which we preserve, maintain, and renew highway infrastructure will change over the next 30 to 50 years in response to inevitable changes in the level and patterns of usage of the system; innovations in materials, methods, and technologies; the availability of resources; and other external non-transportation-related factors.

While this guide highlights 16 exemplary emerging PMR practices worthy of familiarization and consideration for their beneficial impacts upon highway PMR over this timeframe, a key tenet of this guide is *preparation* rather than *prediction*. This guide recognizes that predicting which practices will be "the next big thing" is impractical; therefore, the guide must accommodate a full range of practices, from those highlighted to those no one has yet perceived.

Preparation is key. Leaders and their agencies should be prepared for a range of future scenarios in which highway PMR evolves and adapts, as well as for opportunities to capitalize on specific practices that can improve efficiency and effectiveness, both for the agency and for the agency's customers. To do so, however, it is necessary to foster an organizational and cultural environment to encourage innovative practices and cultivate innovative thinking.

This guide also serves as a charge to transportation leaders for cultivating an environment that advances desirable innovative practices even when those practices lie beyond their capability to initiate on their own. Many practices will be inherently challenging for transportation agencies, particularly when they are driven by technologies and market forces beyond their domains. This is particularly true when advanced technologies and practices emanate from sectors outside transportation, yet they can provide dramatic benefits to transportation agencies. Advancing the state of the practice in highway PMR under such circumstances will require collaborative efforts and partnerships among peers at the national level and with industry drivers of change that will influence the directions and decisions of agencies regarding such innovative practices.

Definitions of PMR

- *Preservation:* Includes work activities that are planned and performed to improve or sustain the asset condition in a state of good repair. Asset preservation primarily includes preventive maintenance, minor rehabilitation and retrofitting of infra-structure elements [pavements, bridges, intelligent transportation system (ITS) or ITS components], network or area wide enhancements and upgrades, and some aspects of routine maintenance.

  — Preventive maintenance includes a series of cost-effective treatments applied to preserve or extend the service life, retard future deterioration, upgrade to current or improved safety standards, and maintain or improve the functional conditions of existing assets. Both condition-based and regularly scheduled cyclical activities that contribute to extending the useful life of assets are considered preventive maintenance activities.

  — Minor rehabilitation involves non-structural enhancements to reduce aging, restore serviceability, or eliminate surface-initiated, environmentally induced deterioration. Network or area-wide enhancements, such as for pavement strip-ing, lighting components, signs, and guardrails, are also considered as minor rehabilitation.

  — Preservation includes all planned and recurring activities of routine maintenance performed to reduce the deterioration of existing assets.

- *Maintenance:* Describes work activities performed to maintain the general condition of existing assets or in response to specific conditions or events to restore their func-tional state. Maintenance includes some aspects of routine maintenance, as well as corrective and emergency maintenance.

  — Routine maintenance is performed to restore the functional condition of exist-ing assets, such as crack filling of non-working cracks, dust control, spot painting, snow removal, debris removal, mowing and tree removal, fender systems repair, weed and vegetation control, and drainage cleaning.

  — Corrective and emergency maintenance include "reactive" type of work activi-ties performed in response to potential or existing deficiencies that adversely impact the smooth and safe operations and future integrity of the existing asset. Examples include pothole repairs, bridge deck joint repairs, patching and grout-ing, full or partial depth repair, and bridge bearings replacement.

- *Renewal:* Includes work activities performed to fully or partially restore the structural integrity, correct safety defects, and improve the functional capability of the asset.

  — Major rehabilitation involves major work required to enhance or restore the structural integrity of an asset as well as work necessary to correct major func-tional deficiencies and safety defects.

  — Reconstruction involves a complete removal and replacement of a structurally deficient or functionally obsolete asset with an equivalent or enhanced service capacity.

Guide Overview

This guide is organized into two main sections. The first section provides information that sets the stage for innovative practices. The second section describes an evaluation and improvement tool offered to help better foster such practices within the agencies. A brief description of a practitioners' guide, also prepared in this project, is also provided. Part C, Figure 1 illustrates how leadership may access the guide's sections and tool. In this figure and elsewhere in the guide, the terms emerging and/or innovative practices are used interchangeably.

Preparing for Emerging and Innovative PMR Practices

The guide presents a brief study background and then highlights important trends in "The Future Context," with a perspective that culminates in the vision presented. This section also includes an overview of emerging PMR practices and summarizes 16 emerging/innovative practices that exemplifies a limitless range of possibilities to stimulate interest among leaders in enhancing their agency's ability to cultivate and deploy such practices. Many of these practices are innovative particularly when viewed from today's context and given the long-range (30 to 50 year) planning context of this guide. Recognizing that advancing such innovative practices requires an in-depth understanding of potential benefits and costs, both external to customers and internal to the agency, this section also includes a discussion on "Making the Case for PMR Innovative Practices."

Advocacy for embracing emerging practices including innovation can occur in both a top-down and bottom-up manner by agency leadership and by practitioners. It involves communicating and cultivating knowledge gained from awareness of emerging and innovative practices. Therefore, this section also includes perspectives on "The Importance of Leadership" as well as a discussion of "The Importance of Practitioner Pressure." The benefits from a certain degree of competition among peers, in concert with high levels of collaboration, are also discussed under "Peer Agency Pressure and the Opportunities Presented."
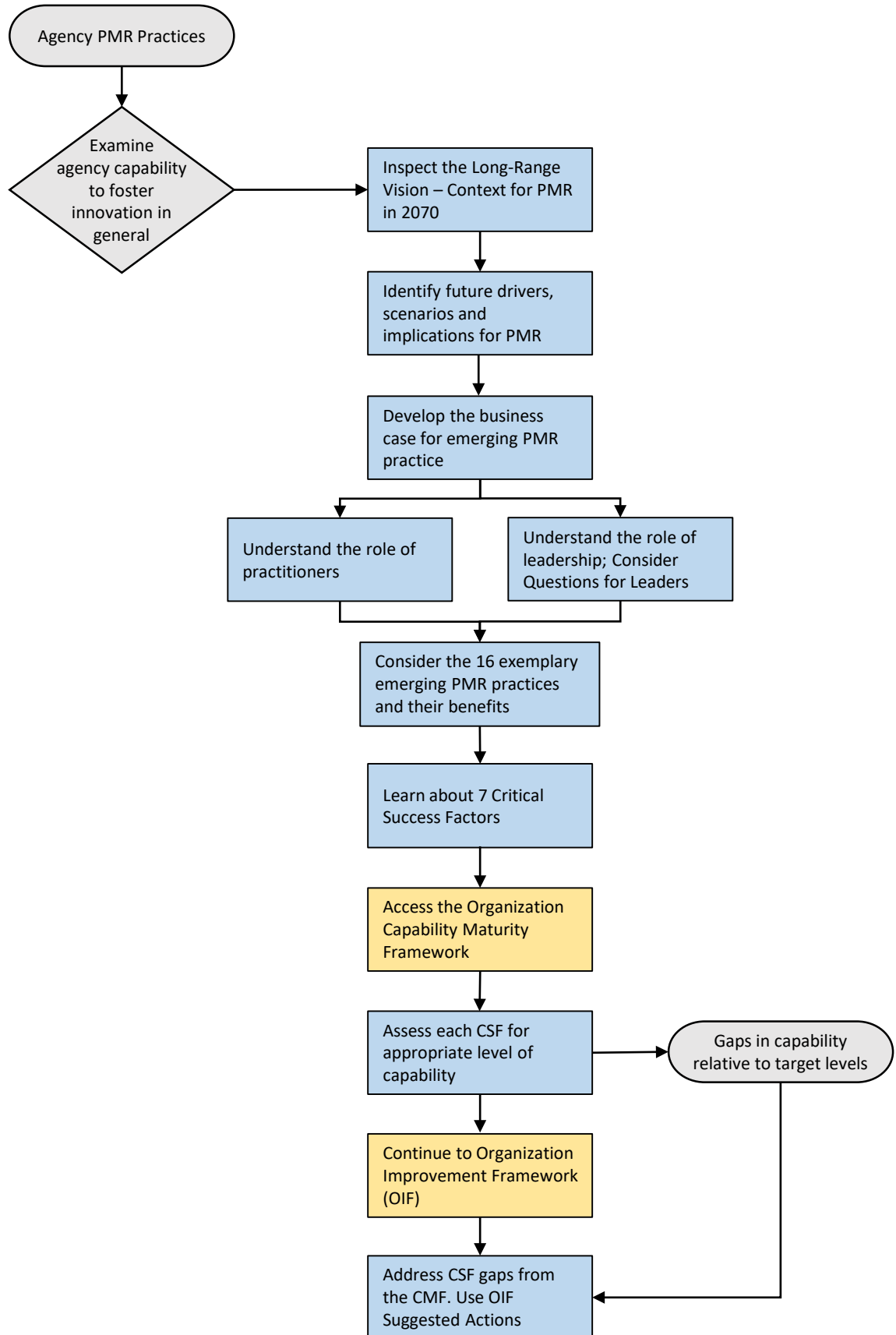
The section also introduces seven Critical Success Factors (CSFs) deemed essential to fostering innovative practices generally within the agency and to advancing specific practices. These CSFs form the basis for an assessment tool (presented in the guide) to help agencies assess their capability for innovative practices and identify actions to better foster such practices across the enterprise.

Fostering Innovative Practices Within the Agency

The assessment tool in this guide is a set of evaluation and improvement frameworks: the Organization Capability Maturity Framework (CMF) and the complementary Organization Improvement Framework (OIF). Their intent is to examine general capabilities at any level of the organization to foster innovative practices, ranging from the enterprise as a whole to individual units within the agency. The Organization CMF provides a straightforward, criteria-based structure to determine where the agency stands against the seven CSFs. This assessment can identify gaps in capability; the OIF provides a framework for enterprise-wide actions to address those gaps.

Remarks on the Practitioner's Guide to Emerging Highway Preservation, Maintenance and Renewal Practices

This guide concludes with a short section suggesting reasons why discipline leaders and technical managers may want to use the Organization CMF. The Practitioner's Guide also includes a different "emerging PMR practice-specific" CMF that may interest agency leaders in deciding whether and how to advance a specific emerging PMR practice with broad-based implications across the enterprise.

Part C, Figure 1. How to use the leadership's guide.

Preparing for Emerging and Innovative PMR Practices

Study Background

The following steps were taken in the preparation of this guide:

- Identification of factors and trends that could significantly influence highway infrastructure PMR needs over a 30 to 50-year horizon.
- Identification of an initial "long list" of more than 60 potential emerging and innovative PMR practices that could significantly improve the ability of transportation agencies to address those needs.
- Shortlisting and characterization of 24 emerging PMR practices according to the following criteria:
  - Responsiveness to future context,
  - Departure from current practice,
  - Degree of impact, and
  - Plausibility.
- Consultation with an outside group of transportation agency and industry professionals regarding the outline for the 16 emerging/innovative PMR practices.
- Assessment of the benefits of embracing the emerging PMR practices for organizations when considered in the context of a vision for the nation's future highway network in the year 2070.

This guide begins with the following long-range vision for PMR, which looks 50 years into the future to set the context for how emerging and innovative PMR practices will play a vital role and how transportation agencies should think strategically and tactically to embrace and advance such practices.

A Long-Range Vision—Context for PMR in 2070

In the year 2070, the nation's multimodal transportation system remains anchored by a ubiquitous highway network that has been transformed over the past half-century despite chronic limitations of available resources. These transformations have dramatically improved the safety, efficiency, reliability, and durability of what is now more accurately characterized as the vehicle-highway network, or VHN. The term VHN reflects a paradigm shift toward an ever-increasing integration in the relationship between infrastructure and its users through automated, self-driving vehicles, as well as vehicles connected to one another and to the roads they traverse.

The magnitude of changes can be measured using the pervasive data that have been collected on both the usage and the infrastructure side of the VHN since the year 2020 when performance measurement came into its own among transportation organizations. While the data reflect considerable variation from place to place, a view of national trends provides the best way to appreciate how far we have come over the past five decades.

The most dramatic and revered change has been the extraordinary reduction in the absolute number of road-related fatalities and personal injuries despite a more than 70 percent growth in vehicle miles traveled (VMT). Over the same period, we have significantly expanded the carrying capacity of existing roads and dramatically improved overall reliability (as measured by point-to-point travel time consistency within peak and off-peak time periods). Even more important to customers than these VHN-centric measures of performance is the daily liberation of many minutes, and occasionally hours, from the time-consuming and stressful task of "non-pleasure" driving to the more useful and satisfying time that can now be spent as vehicles self-navigate the network virtually flawlessly on roads and bridges that are in a significantly better state of repair than they were 50 years ago.

The role of streets and highways—particularly among the 20 percent that compose arterials and carry 75 percent of the vehicle miles—has been significant in achieving these breakthroughs in safety, reliability, and efficiency. The physical network has been transformed through innovations in PMR materials, tools, approaches, and technologies. This is manifested by increased infrastructure instrumentation that has facilitated vehicle-to-infrastructure (V2I) communication, as well as by breakthroughs in the efficiency and cost-effectiveness of PMR practices resulting from such innovations as the following:

• Predictive-proactive PMR regimes for roadway assets,

• Remote sensing and structural strength monitoring,

• Self-diagnosing, reporting, and work ordering,

• Hyper-performance materials that provide virtually perpetual highway infrastructure,

• Artificial intelligence to manage daily operations and respond to disruptive events,

• 3D printing and quick turn-around replacement of prefabricated repair elements for riding surfaces, and

• Use of robotics in repair and construction activities.

A three-fold increase in the expected life of bridges and a doubling on the average structural life of pavements, despite significant increases in permissible axle and gross vehicle weights, have led to improved conditions and performance with little or no increases in real dollars available on an annual basis. A 50 percent reduction in the average elapsed time between identifying the need and completing repairs, and a 75 percent reduction in average downtime during which travel lanes are taken out of service for PMR activities are reasons why national surveys have shown significant improvements in customer experience and satisfaction.

Having reaped the benefits of 50 years of research and development (R&D) in innovative PMR materials, tools, approaches, and technologies, with still more to come as we continuously strive to improve, we can now say that our VHN is dramatically safer, more efficient and reliable, and in better condition than it was half a century ago, with little or no increase in real (inflation-adjusted) PMR costs. The seeds that were sown over this period have produced a bountiful harvest.

The Future Context

The vision presented in the previous section suggests that a robust and increasingly resilient and adaptive network of streets and highways will continue to be needed into the future. The building blocks of this network will continue to include pavements, bridges, tunnels, drainage systems, and other components of highway infrastructure that are available in today's world and will remain available in the future. However, the trajectories of various trends and driving forces make it clear that the specific ways in which we maintain, preserve, and renew highway infrastructure will change significantly over the next three to five decades. These changes will occur in response to inevitable changes in the level and patterns of usage of the system; innovations in materials, methods, and technologies; and availability of resources—financial and human—to investigate and implement emerging and innovative practices.

While the mix of drivers of future change is likely to vary, the ensuing scenarios must cover the entire domain of PMR-related possibilities. It is not feasible to define these scenarios precisely over a 50-year timeframe beyond describing general trajectories in trends (e.g., growing population, increasing traffic), but nor is it necessary. Rather, the implications of these drivers and scenarios help inform what emerging PMR practices may be most beneficial to address the implied challenges and risks agencies will face as they navigate an evolving and uncertain future.

Part C, Table 1 provides a high-level summary of key future drivers and their implications for PMR needs. If not already engaged, agencies should track these drivers and monitor the implications on their PMR needs in a concerted effort to stay ahead of the curve and proactively seek opportunities to apply emerging PMR practices that are responsive.

Part C, Table 1. Future drivers and implications for PMR needs.

Future Drivers	Implications for Future PMR Needs
Demographics, Economics, and Transportation Demand	Ability to accommodate growing traffic, reduce traffic congestion and disruption, improve highway safety, and ensure system reliability
Resilience and Security: Natural and Man-made Threats	Ability to adapt to climate change impacts, manage assets and risks, and provide rapid response
Stewardship: Natural Resources and Communities	Need for sustainable and environmentally responsible strategies, materials and processes to reduce energy consumption, emissions, depletion of natural resources, community impacts, and environmental footprint
Financial Resources: Sources, Priorities, and Effectiveness	Need to explore newer funding strategies more rigorously and objectively define priorities and to maximize cost-effectiveness through improved operational efficiencies and performance of infrastructure assets
Technology: Materials and Methods	Need for improved materials and methods to extend the life expectancy and minimize life-cycle costs of assets
Technology: Information and Analysis	Need for improved technologies, tools, and algorithms to collect, manage, visualize, and interpret data
Vehicles Characteristics and Operations	Ability to accommodate emerging trends in vehicle technologies, characteristics and operations
Institutional Changes and Choices	Need to foster positive changes as well as adapt to evolving institutional arrangements, human resources, and customer expectations

Making the Case for PMR Innovative Practices

While there is a certain qualitative "feel-good" benefit that may accompany doing something that is new and different, being innovative just for its own sake is not sound justification. There must be reasons that are sound and practical to justify the investment and commitment of time and energy required to advance from the state-of-current practice to the leading edge. This is true of innovation in general, but there are unique reasons as to why advancements in PMR practices are important for agency leaders and practitioners to consider:

- PMR activities are a priority,
- PMR activities consume a large share of highway agency budgets
- PMR activities are never-ending,
- PMR innovative practices can attract talent,
- PMR innovative practices are pathways to opportunities:
  - Provide good customer service,
  - Enhance agency credibility, and
  - Attract necessary resources.

PMR Activities Are a Priority

Taking good care of existing assets that are essential to a highway agency's mission is obviously fundamental to its success. It is difficult to imagine how to make a case for any higher priority, other than responses to emergencies. What could be more basic than achieving well-founded performance goals for physical condition, safety, mobility, reliability, and resilience? Nonetheless, it is common for highway agencies to be pressured to divert resources that should be allocated to PMR activities toward system expansion projects. This creates even stronger pressure to become more efficient and cost-effective in fulfilling basic PMR functions.

PMR Activities Consume a Large Share of Highway Agency Budgets

Even where PMR activities are underfunded, they typically consume the largest share of an agency's budget. Advancements toward leading-edge practice in reducing life-cycle PMR costs for achieving a targeted performance outcome should therefore be worth considering. In most instances, the returns on an upfront investment occur over time, and so the pressures of keeping a lid on annual budgets can be a significant restraining force. Nevertheless, if there is to be any expectation of PMR activities becoming less costly over time without compromising on performance outcomes, it must come from new and better ways of doing business. Of course, if the objective is to improve on current performance levels, the "savings" will be in the form of advancements that provide the most cost-effective and efficient means toward that end.

PMR Activities Are Never-Ending

Highway infrastructure wears out over time, and it must always be kept in an acceptable operating condition. This means never-ending investments in PMR activities that may range from snow removal to major reconstruction. Whether they are recurring annual operating expenditures to retain and restore existing service, or periodic capital investments that add years to the useful life of an asset, they never cease. The impact of PMR outlays and the opportunities represented by emerging PMR practices should therefore be viewed not just in terms of annual budgets, but rather over the life cycle of highway assets. This is not always easy to do given the fiscal and political realities of annual budgeting, but it is a vitally important factor in becom-

ing motivated by advancements, particularly those requiring upfront outlays in expectation of downstream benefits.

PMR Advancements Can Attract Talent

It is common for highway agencies to have difficulty in attracting young professionals to preservation and maintenance functions. It is easier to find interest, particularly among graduate engineers, in areas such as highway design, structures, traffic engineering, hydraulics, geotechnical engineering, and construction engineering. All of these areas are connected and essential to PMR advancement. At the same time, actively encouraging the exploration of emerging PMR practices that leverage the leading edges of technology becomes a self-reinforcing way of attracting talent to leadership roles in PMR activities—leaders who see more broadly the need for and benefits of innovative practices, and in turn, improve the likelihood that PMR efforts will continue to attract the necessary talent and potential champions.

PMR Innovations Are Pathways to Opportunities—The "Upward Spiral" of Customer Service, Credibility, and Resources

While there are myriad indirect benefits from a safe and efficient highway system relating to economic well-being, vitality of communities, societal equity, and environmental quality, these are largely derivative of more directly measurable performance goals such as safety, mobility, access, reliability, and resilience. PMR activities affect all of these areas. Therefore, any opportunity to improve highway agency PMR practices represents an opportunity to enhance the experience of those who use or are affected by the streets and highways under the agency's purview. All such stakeholders may be viewed as customers whose increased satisfaction can be thought of as fueling an upward spiral of improved credibility in the realms of public perception and politics. It is in these worlds that an agency's reputation is formed. Is it well run or poorly managed? Does it provide good service? Is it responsive to evolving needs and shifting conditions? Is it a leader among its peers? Does it deliver value for money? Agencies that fare well in these intertwined perceptions are more likely to be viewed as worthy of the confidence vested in them by stakeholders and by those who control their purse strings. They are also more likely to be supported in their continued efforts to advance their PMR practices toward the leading edge.

In an era of growing emphasis on performance, accountability, and transparency, public agencies cannot afford to be viewed as victims of indifference or inertia when it comes to innovative practices. Those organizations that have kept up with the leading edge practices to provide improved service to customers will become increasingly evident among political leaders and are more likely to receive the resources needed to sustain their upward spiral of continuous improvement.

The Importance of Leadership

Seeking out and implementing innovative PMR practices is not just the job of researchers and practitioners. It requires leadership and an organizational culture that fosters self-awareness, continuous learning, and adaptation to beneficial changes. Those considered in leadership positions include not only the CEO, but also those senior managers who have a seat at the table as decisions are made, who have responsibility for implementing those decisions, and thereby have an impact on the long-term direction and the day-to-day activities of the organization.

It is impossible to isolate innovation-supportive leadership characteristics for PMR alone, and therefore they are addressed in this guide in broader terms. However, since it is quite possible

for PMR functions in general to receive less leadership attention than other, higher profile areas, it is worth focusing on the potential for this occurring and the implications for emerging and innovative PMR practices.

Gaining Leadership Attention for PMR

Not unique to transportation is the all-too-often, yet understandable, consumption of the attention of organizational leadership by the most visible and consequential areas of responsibility—revenues, budgets, operations, system enhancement decisions, stakeholder engagement, politics—to the detriment of areas such as preservation, maintenance, and renewal of the physical plant. These are all frequently viewed as routine and mundane in the absence of pressing issues, and therefore less prominent on the leadership's radar—except when erstwhile low-key PMR issues lead to major problems, such as an unplanned system closure resulting from inadequate attention over time.

When it comes to innovative PMR practices, it may require special effort to ensure that this vital but often less visible area assumes a position of priority for the attention of leadership. The following section discusses the responsibility among PMR practitioners to find ways of gaining the attention of organizational leaders. In addition, leaders must be sensitive to the potential tendency of affording insufficient attention to PMR areas and the unfortunate consequences that can result from "under-engaging" in PMR issues.

How Important Is Front-Office Engagement to Front-Line Innovation?

It is possible, although not as likely, for innovative PMR practices to occur in organizations in the absence of active leadership support. In their 1982 widely read book, *In Search of Excellence,* Tom Peters and Robert Waterman, Jr., refer to "skunkworks," a term coined by Lockheed during World War II, which Wikipedia defines as "…a group within an organization given a high degree of autonomy and unhampered by bureaucracy, with the task of working on advanced … projects." Skunkworks are considered incubators of innovation populated by self-starting champions who work apart from the mainstream organization to come up with game-changing ideas that offer dramatic improvements to products and processes. For skunkworks to have an impact, however, the fruits of their efforts must affect the enterprise, which means that organizational leadership must buy in. Some leaders have been known to encourage skunkworks not only in the hope of achieving transformational breakthroughs, but also to keep mainstream units who are engaged in process and product improvements on their toes.

For innovative practices to flourish in an organization, leadership must be on board, whether through highly visible and encouraging actions or through less visible but no less important support for champions who will challenge the status quo in a quest for continuous improvement. Innovative practices must not only be encouraged and supported, but must not be impeded by the enterprise as a whole and all of its component parts, such as:

- Planning and resource allocation processes,
- Procurement and administrative procedures,
- Management systems and information technologies,
- Recruitment and promotion practices,
- Education and training, and
- Willingness to accept prudent risks where the probabilities of success and anticipated returns on investment are based upon systematic testing and evaluation.

Some degree of organizational inertia and hesitancy (if not outright hostility) to change are virtually inevitable barriers to change, even in top-notch organizations.

External Communication

In addition to instilling and sustaining an environment for innovation within the agency, leaders must communicate beyond the agency to generate understanding and support for investment and change, and in particular, to obtain endorsement and resources from outside influencers (e.g., legislators, private industry, customers, etc.). Leaders will ideally continuously and consistently educate these external audiences on the benefits and progress (or failures) with innovative practices. Successful communication consists of framing the proposed innovation in terms of the following:

- How it solves an existing, well-defined problem;
- How the outcomes tie to agency strategic initiatives or goals;
- How it will improve internal efficiency and effectiveness; and
- How the customer experience will be enhanced.

Top-Down Perspective

Leaders understand the big picture at the enterprise level and are in the best position to recognize opportunities for innovative practices that cut across and extend beyond organizational boundaries. While interest in specific innovations is often viewed more in the domain of the practitioner, leaders are in the best position to facilitate a multidiscipline, interoffice system approach to identifying the value and impacts of innovations that cut across agency disciplines and functions. This includes anticipating potential differences and facilitating a collaborative approach, both within and where appropriate, beyond the agency's boundaries.

Bottom-Up Listening

Cultivating a welcoming atmosphere for innovative practices also calls for leadership that listens and expects others in leadership and management positions to listen to customers, practitioners, peers, and purveyors of innovation in the private sector and academia. It requires leaders that encourage feedback and ideas from staff at all levels, including those at the front lines who carry out the work and often see firsthand the greatest need and potential for significant improvement. If the perception among front-line workers is that they are expected to do as they are told without making waves that upset the status quo, then the organization is losing one of its most potent sources of input about where innovative practices are needed and which practices are most likely to succeed.

Leaders must balance numerous priorities and often cannot afford to devote extensive time to exploring all issues in depth. They may not possess a background steeped in the technical specifics of PMR. As a result, they must receive and act upon the counsel of PMR practitioners who can provide the necessary understanding and recommendations of the importance of PMR improvement.

Walking the Talk

While virtually none in leadership positions would claim to be anything but supportive of advancements and innovative practices, as with any other aspect of leadership, it is whether

leaders "walk the talk" that counts in the end. Leaders talking up the value of advancements is an important step, but "taking the walk" requires a lot more than just talk. Walking the advancement talk means leaders who do well in responding to probing questions on advancements; Part C, Table 2 provides a list of such questions.

Part C, Table 2. Questions leaders should ask themselves to better position themselves for taking advantage of emerging and innovative PMR practices.

- *Are you in touch, at least in general terms, with where key parts of the organization stand in their current PMR practices compared with peers, compared with state-of-the-art and leading-edge practices, and compared with those that are just beginning to find their way into practice?*

- *Do you understand the relationship between how the organization does business today and the external drivers that will influence how it must do business tomorrow to fulfill customers and stakeholder expectations?*

- *Are you fostering a culture that encourages objective and collaborative self-scrutiny at all levels, a passion for learning and continuous improvement, and the unwavering obligation of leadership and management to seek out ideas from front-line staff?*

- *Does interest in improvements arise from bottom-up champions?*

- *Are there regular processes in place that result in an agency-wide perspective on the relative need for, value from, and priority of advancing innovative practices?*

- *Are you recruiting, screening, and advancing staff at all levels, from the front lines to the front office, who grasp the importance and are fully supportive of a forward-looking culture of improvement?*

- *Are analytical processes in place to evaluate potential benefits and costs (both internal to the agency and external to customers) in reaching investment decisions into innovative practices?*

- *Are performance metrics in use that identify current, targeted, and actual outcomes?*

- *Are you confident that systems and programs are in place that support rather than impede the never-ending search for better ways of doing business?*

- *Do you provide the necessary resources to support a learning organization and the testing of innovative approaches?*

- *Do you recognize and accept that inherent in innovative practices is the risk of falling short of expectations, while learning from experiences that reduce the risk over time?*

- *Do you celebrate successes internally in ways that demonstrate the importance of seeking out beneficial practices, and externally in ways that build respect for and confidence in the agency?*

Leading Edge Versus Bleeding Edge

A conscious strategy among agency leadership may be to strive to be on the leading edge of best practices, proven in peer agencies with similar circumstances, while simultaneously avoiding the "bleeding edge" where costs and risks associated with potential innovative practices are likely to be greater. This may not be a bad strategy. A highway agency leader recalled communicating with his leadership team that being in second place among peers in leading-edge practices across all agency functions would virtually ensure being in first place overall as an agency. The implicit assumption is that few, if any, agencies become innovation leaders across all functions. Rather, those that strive to be in the forefront of innovation more typically focus on a select number of areas that are important to them and in which they have made significant investments to establish and sustain a critical mass of expertise and capability.

Get the Ball Rolling

Even where the strategy is to learn and adapt from the experiences among pioneering peers, or from developments led by industry (as in the case of connected and automated vehicles and construction robotics), it is important to "get started" in terms of awareness, keeping up with advancements, and gearing up for a technology transfer. This can be done by making early investments in staff and other required resources given the lead times typically required between a decision to move forward and ultimately achieving the sought-after outcome. Failure to start the ball rolling, even when the innovative practice may be some time away or seemingly outside the domain or control of the public agency, could result in drifting toward the back of the pack or rushing into or reacting to a practice for which the agency may be not well prepared.

This hesitancy or inability to get started may be due to the short-term thinking of agency top-level leadership to focus primarily on short-term problems, and to invest energy and resources toward innovative practices whose benefits in years to come they may be unlikely to experience. Another constraint that may dampen interest in such practices over the long run stems from the process—and the politics—of annual budgeting and the discounting of long-term benefit characteristic of agency as well as elected leaders. This has led to enormous pressures to focus on "first" or initial costs and quick successes in making investment decisions. The "first cost" approach takes the emphasis away from analyzing benefits and costs on a life-cycle basis and discourages upfront investments in anticipation of long-term outcomes.

Winners, Losers, and Vested Interests

PMR innovative practices may ultimately result in cost savings and service improvements that accrue to the benefit of public-sector agencies and the customers they serve. However, they may have short-run or long-term negative impacts on some individuals or groups who have a vested interest in the status quo and who may use every tool at their disposal to steer a highway agency away from such beneficial practices that would damage their interests. Similarly, those who may gain from certain changes may press for those changes, whether or not net benefits are in the offing. What both potential winners and potential losers have in common is the tendency to exaggerate their claims and apply pressure to agency and political leadership in a manner that might tilt the playing field in their direction. None of this helps the case for objective, merit-driven innovative practice, but it reflects a reality that often must be addressed.

Change Management

Finally, it is important for agencies to consider the need for change management strategies when implementing innovative practices. The potential for resistance to change from legacy systems and practices should not be ignored, particularly among practitioners whose skillsets may no longer be needed and from managers whose area of responsibility may be diminished. An essential aspect of change management is finding and designating internal champions to navigate the complex maze of formal approvals and informal buy-in through collaborative and motivational approaches that can build support and overcome resistance without leaving a destructive and potentially counterproductive wake. Top management support and staying power is critical to sustain not only the investment of funding, but also the investment of time and energy, which can be just as scarce, when dealing with barriers to change.

The Importance of Practitioner Pressure

While this guide is focused on leadership, it is important to consider the role of bottom-up practitioner pressure to gain the attention of leaders with respect to opportunities for practices worthy of consideration. It is assumed that the vast majority of leaders will appreciate the value of energized, thoughtful, proactive practitioners who will share their perspectives on possibilities for advancements. Indeed, leaders in organizations historically characterized by a top-down culture may wish to consider strategies that encourage bottom-up initiatives and feedback, reflective of a culture particularly attractive to more recent generations of young professionals.

Seasoned practitioners who specialize in technical disciplines know that to advance the state-of-the-practice toward the leading edge requires not only a threshold of technical expertise, but also an enterprising, proactive approach that results in upward pressure on leadership to invest in innovative practices. This is particularly true for PMR-related activities, where many of the opportunities for these practices are highly specialized and may not appear on the radar of even the most progressive and enlightened leaders.

If agency leadership has done its job well in recruiting and advancing top-tier technical talent and in fostering a learning culture that seeks out and welcomes the opportunity to test new ways of doing business, there will inevitably be a bottom-up, practitioner pressure that complements and amplifies top-down agency leadership to encourage advancements. The most daunting challenge for practitioners lies in advocating for innovation in an organization whose leadership and culture may fall somewhat short of these ideals.

Seasoned practitioners understand that they cannot rely on "leadership pull" alone to advance innovative practices. The case can be made that "practitioners' push" is perhaps even more important. With the support of practitioner champions, advancements can occur even in an organizational culture somewhat indifferent to fostering innovation. Alternatively, without practitioner champions at least receptive, and acting as strong advocates, no amount of top-down initiative can force these advancements.

Champions of Advancements

While the major waypoints on the road to innovative practices have a certain commonality—awareness, advocacy, assessment of benefits and costs, assessment of capability, adoption, and action plan—there is no standard process to reach and progress through those waypoints. The specific route can and usually will involve twists and turns, starts and stops, successes and setbacks. That is why innovation champions are an essential part of embracing new approaches and advancing to the leading edge. Innovation champions may come from any quarter. Typically,

they are practitioners who are excited about a prospective innovation in their area of expertise that could represent a significant step forward in enhancing the agency's efficiency and effectiveness. The best innovation champions are wellsprings of passion, pressure, and persistence about the innovation that has captured their interest. They are also realists who recognize that not everyone will be as enthusiastic as they are, and that it will require focus, fortitude, and the ability to communicate their ideas and address the concerns of others to succeed in advancing a new and innovative way of doing business.

Just as leaders must build trust with external stakeholders by communicating the benefits and progress (or failures) with innovative practices, practitioners must brief and educate leadership, who may have a limited background on the technical details of PMR and limited time to devote to the subject. Presentations and discussions with leadership need to be clear, concise, and to the point, and tailored to their particular interests and concerns, which must be researched and anticipated. Involving leadership at key points of any PMR peer exchange activities is beneficial to both groups. As with leaders' communication, innovative practices need to be framed in terms of the following:

- How it solves an existing, well-defined problem,
- How the outcomes tie to agency's strategic initiatives or goals,
- How it will improve internal efficiency and effectiveness, and
- How the customer experience will be enhanced.

Practitioner pressure from an innovation champion is most effective in combination with supportive technical discipline managers (e.g., section or branch chiefs) who have technical knowledge, a broader perspective, and access to resources and the decision-making process. In fact, the innovation champion may be the discipline manager. Having two or more co-champions is also a possibility. There is strength in numbers, but ultimately it becomes important for one person to be the initiator if the early stages of upward pressure and the downstream process of development and deployment are to proceed at a healthy pace. Although there are clear benefits of innovation champions staying with the effort from inception to adoption, there may be times when the champion role is given to another, just as inventors may not become entrepreneurs and entrepreneurs may not always sustain an enterprise beyond the start-up phase. Similarly, the upward pressure may need to continue past the early stages to ensure that well-meaning launches do not prematurely fail, particularly when changes in staffing occur or counter-pressures from skeptics and status-quo advocates take root.

Peer Agency Pressure and the Opportunities Presented

State transportation agencies enjoy close interrelationships at the technical discipline level and the leadership level through AASHTO and four regional counterpart organizations. These connections among peer agencies and peer professionals provide invaluable insights, as well as opportunities for practitioners to advocate for PMR innovative practices and for collaboration in advancing them. Neither practitioners nor agency leaders relish being seen by their peers or by their stakeholders as lagging behind others who operate under similar circumstances. This phenomenon has been a key driver of the longstanding desire among most transportation agencies and individual leaders and discipline managers to advance the state of their practices. All state transportation agencies aspire to be "above average." The opportunities stemming from these relationships include the following:

- Identifying PMR innovative practices being advanced among peer transportation agencies and determining potential relevance and value added on the home turf.
- Soliciting peer agency experience with specific practices to obtain objective feedback and to temper less-than-objective claims from innovation advocates or critics.
- Providing "ammunition" in advocating advancement of a PMR practice in the home agency.
- Exploring possible partnership arrangements with peer transportation agencies to mitigate risks and spread the costs of advancing leading-edge practices.

Overview of Emerging PMR Practices

Part C, Tables 3 through 18 provide brief summaries of the 16 PMR-related emerging and innovative practices identified through a process of evaluation and prioritization during the research for this project. They represent a curated selection of the most consequential emerging PMR practices deemed plausible over the next 50 years, as determined through extensive research and advice of a panel of PMR professionals. These are only examples of virtually limitless emerging PMR practice possibilities. However, familiarity with this subset will go a long way to advance an understanding of emerging PMR state-of-the-practice and lend weight to the need to foster an agency environment in which these practices, or others, can thrive and deliver benefits to the agency and its customers. The summaries focus on what each emerging PMR practice is and does, the strategic value or benefit it can provide, and its plausibility in terms of being an incremental or radical departure from current practice.

Part C, Table 3. Hyper-performance materials.

Emerging PMR Practice	Hyper-Performance Materials
Infrastructure Disciplines Covered	Pavements, Bridges, Tunnels, Ancillary Assets
Description	• Materials designed to have better strength, durability and/or workability properties than corresponding traditional materials • Examples: ultra-high performance concrete, self-healing asphalt, and ferrite-bainite steels • Newer variations with advancements in nanotechnology
Strategic Value	• Reduction in the need for frequent maintenance, major structural rehabilitation, and reconstruction activities • Greater resiliency and adaptability to climate change and extreme weather, as well as growing traffic and heavier vehicles • Significant reductions in life-cycle costs • Reductions in the use of depleting natural resources, reduced energy consumption and lower emissions, and lower asset life-cycle's environmental footprint
Plausibility	• Incremental advancement for an agency • Breakthroughs currently in exploratory research and development stages

Part C, Table 4. Connected V2I technology providing communications between passing vehicles and roadside units.

Emerging PMR Practice	Connected V2I (Vehicle to Infrastructure) Technology Providing Communications Between Passing Vehicles and Roadside Units
Infrastructure Disciplines Covered	Pavements, Bridges, Tunnels, ITS Equipment, Ancillary Assets
Description	• Collection of information by infrastructure from vehicles, analysis, and communication to all vehicles and to systems managers through the infrastructure—provides upstream conditions, traffic control, flow control and roadway physical conditions
Strategic Value	• Numerous applications supplement onboard automation to eliminate human error, increasing safety, and providing greater throughput • Significant impacts on traffic flow, VMT, and trip length—all of which may impact asset deterioration cycles or suggest design modifications (e.g., restriping for narrower lanes)
Plausibility	• Technical challenges (e.g., standards, security, liability, privacy) • Requires public-sector owner/operators to be directly in the service provision loop • Technical capacities required of agencies (e.g., systems engineering) • Limited pilots underway along with development of FHWA guidance

Part C, Table 5. Perpetual/long-life highway infrastructure.

Emerging PMR Practice	Perpetual/Long-Life Highway Infrastructure
Infrastructure Disciplines Covered	Pavements, Bridges, Tunnels
Description	• Highway assets whose underlying physical elements last for extremely long periods of time with proper, periodic PMR treatments • Example: bridges whose foundation and superstructure are well protected and preserved with only deck treatments required from time to time
Strategic Value	• No major structural rehabilitation or reconstruction activities required • Only periodic maintenance and preservation activities to address routine wear and tear • Higher initial investments during construction but lower life-cycle costs • Sustainability benefits
Plausibility	• Necessary to overcome perennial pressure to minimize initial investment costs • Need to explore opportunities for innovative procurement and financing alternatives to overcome year-one budgetary constraints • Will benefit from evolution of improved structural design methodologies and advanced roadway materials

Part C, Table 6. Integrated building information modeling (iBIM) for highways.

Emerging PMR Practice	Integrated Building Information Modeling (iBIM) for Highways
Infrastructure Disciplines Covered	Pavements, Bridges, Tunnels, ITS Equipment, Ancillary Assets
Description	• Integrated electronic system with vendor-independent, interoperable data governed by common data standards, supported by a secured cyber infrastructure of fully automated connectivity and web- or cloud-based applications • Used to collect, organize, and access all facility asset-related data and information during its life cycle, including PMR activities
Strategic Value	• Current practice for managing electronic information is with commercial standalone systems, typically siloed along the lines of asset life-cycle function • iBIM will break down these silos becoming a one-stop way of storing, retrieving and archiving all asset-related information • More efficient and cost effective asset management processes and outcomes
Plausibility	• Will represent a huge leap in facilitating PMR activities and take many years • Trends point to this direction (e.g., advancements in geospatial and surveying technologies, e-construction, digital engineering designs, etc.) • Efforts underway to develop data standards

Part C, Table 7. Connected vehicle applications to supply real-time conditions information.

Emerging PMR Practice	Connected Vehicle Applications to Supply Real-Time Conditions Information
Infrastructure Disciplines Covered	Pavements, Bridges, Tunnels, ITS Equipment, Ancillary Assets
Description	• Use of vehicles as probes for sensing key infrastructure condition characteristics (e.g., pavement condition) • Application of onboard sensors (accelerometers, inertial sensors, suspension motion detectors) to capture and communicate individual vehicle response to operating conditions
Strategic Value	• Augments conventional passive infrastructure measurements • Data can be analyzed for their inferential relationships with actual physical conditions • Increased data available for asset management decision making
Plausibility	• Will require major data management/modeling effort • Likely to depend on the market penetration of onboard dedicated short range communications (DSRC) and transportation agencies' uptake on accommodating V2I data collection • External technological and institutional changes necessary (e.g., additional onboard sensor technology, industry standards to support uniformity, "crowd sourcing" data, etc.)

Part C, Table 8. Remote sensing systems—PMR applications.

Emerging PMR Practice	Remote Sensing Systems—PMR Applications
Infrastructure Disciplines Covered	Pavements, Bridges, Tunnels, ITS Equipment, Ancillary Assets
Description	• Use of smaller unmanned aircraft systems (drones) to monitor the composition, condition, and performance of highway assets • Devices may include infrared, thermal, multispectral, hyper spectral, and heat capacity mapping for optical imaging, and ultra-wide beam synthetic aperture radar for non-optical imaging
Strategic Value	• High resolution imagery that is less expensive, faster, and larger in area coverage • Improved predictive, detection, and sensing capabilities to update asset inventories and monitor conditions in real time
Plausibility	• Incremental advancement to highway agencies • Introduces new regulatory issues relating to air space use • Technical issues: obstruction and radio disturbances in urban areas, need for more sophisticated data processing

Part C, Table 9. Machine learning—artificial intelligence for asset management.

Emerging PMR Practice	Machine Learning—Artificial Intelligence for Asset Management
Infrastructure Disciplines Covered	Pavements, Bridges, Tunnels, ITS Equipment, Ancillary Assets
Description	• Machine learning to recognize patterns and trends, and gain insights from asset performance data that may otherwise have been lost in statistical variability • No explicit need to program where and how to look for such patterns and trends
Strategic Value	• Current predictive models are mostly designed to analyze trends based on formalized, pre-established, "deductive" knowledge of variables • Machine learning applications can analyze complex data sets, investigate recent and long-term trends in asset behavior, and use this information to build more reliable, robust, data-driven decision support systems • Can improve asset management practices, lower assets' life-cycle costs, and optimize resource allocation of funds
Plausibility	• Significant improvement to a highway agency • Much is known from application to online retailing, genetics, finance, health informatics

Part C, Table 10. Predictive-proactive maintenance regime for roadway assets.

Emerging PMR Practice	Predictive-Proactive Maintenance Regime for Roadway Assets
Infrastructure Disciplines Covered	Pavements, Bridges, Tunnels, ITS Equipment, Ancillary Assets
Description	• Proactive, dual source assessment and intervention process that optimizes maintenance regimes for assets, taking into account their criticality and potential consequences of asset failure • Optimizes timing of preventative maintenance by tracking actual versus predicted condition and performance • Results in customized, "just-in-time" preventive maintenance work programs that minimize life-cycle costs
Strategic Value	• Improves upon current reactive and (scheduled) preventative maintenance • Avoids spending money before the optimum point of intervention and failing to exploit useful life remaining in an asset • Ability to adjust the timing of maintenance activities at a reliability level commensurate with the criticality of assets and agency performance goals
Plausibility	• Next generation advancement in maintenance practices • Linked to advancements in IT, geomatics, and geophysical systems and sensor technologies for highway condition assessment

Part C, Table 11. Automated enforcement for work zones.

Emerging PMR Practice	Automated Enforcement for Work Zones
Infrastructure Disciplines Covered	ITS Equipment, Transportation Systems Management and Operations (TSMO)
Description	• Application of speed enforcement, queue detection, speed management, reduction in workforce exposure, traffic data analysis, incident detection, and traveler information on a network basis—to manage work zones • Use of V2I technology to facilitate these tools • Potential application of automated systems to install raised pavement markers, automated cone deployment system, mobile barriers, remotely operated lane barriers, and work space intrusion warning
Strategic Value	• Improved safety for travelers and highway workers • Reduced cost of enforcement • Increased speed of construction from greater spatial margins of worker safety that enable less constrained work zone activity, work zone systems relocation flexibility, and enhanced capabilities for nighttime construction • Reduced construction disruption to traffic flow and speeds
Plausibility	• Need to address public concerns about privacy due to photo enforcement or video surveillance, and reliability of technology • Opportunity to leverage advances in TSMO applications such as Integrated Corridor Management

Part C, Table 12. Structural health monitoring.

Emerging PMR Practice	Structural Health Monitoring
Infrastructure Disciplines Covered	Pavements, Bridges, Tunnels, Asset Management
Description	• Condition and damage detection and characterization strategy for structures • Uses real-time continuous collection and monitoring of mechanistic responses, structural damage, asset usage, and condition • Involves wireless enabled, self-calibrating compact-sized sensor packs with high-fidelity hardware and low power requirements
Strategic Value	• Could enable a centralized asset monitoring center connected with a dispersed network of sensor systems • Self-diagnosing, self-reporting, and work ordering infrastructure system possible when integrated with the "Internet of Things" (IoT) and artificial intelligence applications
Plausibility	• A radical advancement for highway agencies • More research and pilot studies are required • At least one deployment currently under experiment (United Kingdom)

Part C, Table 13. Construction robotics.

Emerging PMR Practice	Construction Robotics
Infrastructure Disciplines Covered	Pavements, Bridges, Tunnels, Ancillary Assets
Description	• Advanced form of automation that focuses on mechanizing construction processes with no or little human intervention
Strategic Value	• Potential to evolve to automatically detect functional and structural conditions of assets, analyze collected information, make appropriate PMR related decisions and execute them in the field • Possible integration with geophysical technologies, remote sensing systems, and micro-electromechanical–based condition/health monitoring systems • Increased productivity, automatic detection and fixing, reduced materials and workmanship defects, reduced waste of natural resources, energy, and labor costs
Plausibility	• Incremental (e.g., intelligent construction machines) or radical (e.g., humanoid robots) advancement for the transportation industry • Dependent on advancements in material technology, microelectronics and mechatronics, and robot learning • Potential societal and political resistance from moving away from traditional labor—and economic consequences

Part C, Table 14. Artificial intelligence—PMR traffic management applications.

Emerging PMR Practice	Artificial Intelligence—PMR Traffic Management Applications
Infrastructure Disciplines Covered	ITS Equipment, TSMO
Description	• Application of artificial intelligence to real-time traffic flow through advanced algorithms that quickly assess and address problems with an ability to analyze, reason, and learn from different situations, to acquire and retain knowledge, and to respond rapidly to new and changing conditions • Applied to the operation of ITS devices to assist in PMR application scenarios
Strategic Value	• Ability to handle large volumes of data to provide traffic control solutions, congestion management, traveler information, and incident/emergency management • Facilitates faster, adaptive, and dynamic responses to traffic conditions during PMR activities as well as during normal operations
Plausibility	• Incremental advancement for a highway agency but radical from the perspective of myriad possibilities of solutions that artificial intelligence can provide • Heavily dependent on the advancements in computer and cognitive sciences • Investment needed to enhance the capacity of agency workforces and to integrate artificial intelligence into business processes

Part C, Table 15. Enterprise information systems—PMR applications.

Emerging PMR Practice	Enterprise Information Systems—PMR Applications
Infrastructure Disciplines Covered	Pavement, Structures, Ancillary Assets, TSMO
Description	• Unified system of computer applications that provides a platform to integrate and streamline business processes • Organizes business requirements and processes in an integrated, seamless structure
Strategic Value	• Provides a platform to integrate all standalone systems into a single unified system streamlining business processes and information handling • Would include, for example, systems that support planning and programming, financial management and budgeting, real estate, environmental services, procurement, construction, maintenance, asset management, etc. • Seamless integration and avoidance of fragmentation and workflow bottlenecks
Plausibility	• Few barriers in the future as agencies are already moving away from disjointed legacy systems • Requires buy-in and commitment from top management to support change management process • Must engage technical management resources to define system requirements and oversee specifications, procurement, development, deployment, testing, transition, and full-scale operational phases

Part C, Table 16. Self-diagnosing/reporting and work ordering.

Emerging PMR Practice	Self-Diagnosing/Reporting and Work Ordering
Infrastructure Disciplines Covered	Pavements, Bridges, Tunnels, ITS Equipment, Ancillary Assets
Description	• System that automates the asset management process: data collection, asset usage tracking, condition monitoring, performance assessment, intervention diagnosis, treatment selection and timing, work order placement, potential self-performance
Strategic Value	• Overcomes fragmented PMR decision making and execution steps (as listed above) reducing elapsed time between problem diagnosis and work completion • Overall reduction in time and effort to identify and address problems • Lower life-cycle costs, increased production efficiencies, and customer satisfaction
Plausibility	• Radical emerging PMR practice for a highway agency • Many barriers and intermediate steps • Culmination of other emerging PMR practices (many mentioned elsewhere)

Part C, Table 17. Advanced TSMO device and communications systems maintenance.

Emerging PMR Practice	Advanced TSMO Device and Communications Systems Maintenance
Infrastructure Disciplines Covered	ITS Equipment, TSMO
Description	• ITS systems' maintenance enabled by wireless sensors and pre-engineered real-time continuous monitoring solutions that automatically alert the maintenance system at the onset of a developing condition • Reliance upon device-specific databases to apply asset management algorithms
Strategic Value	• Maintenance burden of TSMO and communication devices will increase with their expanding deployment • Intelligent maintenance will make the increased ITS maintenance burden manageable with fewer human resources
Plausibility	• Intelligent maintenance tools and techniques are available from other sectors (defense, health, manufacturing) • Growth in inventory deployment will spur their application in transportation sector

Part C, Table 18. The internet of things (IoT)—PMR applications.

Emerging PMR Practice	The Internet of Things (IoT)—PMR Applications
Infrastructure Disciplines Covered	Pavements, Bridges, Tunnels, ITS Equipment, Ancillary Assets, Maintenance and Construction Equipment
Description	• Network of seamlessly connected physical elements that allows information to be created, communicated, aggregated, and analyzed • Would permit real-time monitoring and management of asset condition and performance as well as real-time management of traffic in PMR work zones
Strategic Value	• Would eliminate redundant data collection, use of multiple formats, organizational siloing, and compartmentalization • Permits ability to collect massive volumes of data, share them instantaneously and seamlessly across groups, and put them into immediate effective use • Example: real-time monitoring of structural condition through the sensors and smart materials embedded in infrastructural elements
Plausibility	• Currently emerging organically, but a radical advancement • Technical and business perspective challenges related to legacy processes, inadequate data acquisition infrastructure, standards and protocols, security

Critical Success Factors (CSFs)

Inertial responses to change among individuals and within organizations are common and must be anticipated if advancements are to occur. It is therefore only realistic to expect that instilling a pervasive and persistent desire to foster innovative practices within a highway agency can be expected to require a significant degree of cultural change within the organization. The adoption of these practices would require either agency-wide or discipline-specific commitments to continuous improvement, openness to new ideas, receptivity to change, and well thought-out change management strategies. As individuals and agencies adopt emerging and innovative practices and adapt their internal operations accordingly, they can begin to understand the logical steps involved in implementation. Agencies can fashion their own unique approach while learning from the experiences of others as they create an internal framework that encourages awareness, advocacy, assessment, adoption, and action plans in the advancement of emerging and innovative PMR practices.

What It Takes to Succeed

Success can be defined as overcoming challenges and risks to fostering and adopting specific innovative practices that provide defined benefits. The challenges and risks associated with such practices can be grouped under internal and external factors.

Internal Factors: The highway industry is a diversified aggregation of national, state, regional, and local agencies; industry and professional associations; private contractors and consultants; vendors and material suppliers; and the academic world of basic research and education. The decentralized and somewhat fragmented nature of the industry makes the widespread acceptance and implementation of such practices among organizations a challenge requiring customized strategies and processes to educate, encourage, convince, demonstrate, and deploy.

External Factors: Myriad external factors, such as market uncertainties and government regulations, influence the acceptance and implementation of innovations among highway organizations.

Many innovative practices are direct or indirect outcomes of the research and development that emanate from other sectors (e.g., information technology, telecommunications, and materials science) some of which are not well known or wholly unknown to the highway community. Adding to perceptions of risk is the sense that highway agencies may have little or no influence over the external technological or regulatory aspects of these practices that might heavily influence implementation efforts and ultimate outcomes. Finally, there are inherent risks associated with whether these practices will prove successful and worthwhile.

These internal and external factors of challenges and risks can be organized around the following:

- Agency Business and Technical Processes: Relates to how innovative practices are approached from both business and technical points of view, including performance awareness and application, supportive systems and programs, funding, and policies related to innovation program development.
- Agency Institutional Context: Relates to internal agency culture, organization, and staff willing and capable of capitalizing on these practices.
- External Collaboration: Involves interaction and collaboration with key communities outside the agency and partnerships with the public and private sector to support these practices.

This guide defines seven CSFs across these categories where challenges and risk must be considered in advancing innovative practices. They form the basis for evaluating and improving agency capability to advance specific PMR innovative practices and to foster innovation.

Awareness

Awareness refers to how in-tune an agency, unit, or individual is with the state-of-the-art and trends in specific areas, and where the agency, unit, or individual is within their practice. Awareness can refer to the context in which the practice applies, including the leading-edge practices, the status of research and development in progress, problems being addressed, and alternative approaches being developed and tested. It can also refer to awareness of a specific practice—understanding what it is, what it does, where it should work well, where it might not apply, and the level of effort and resources required to advance to implementation (staffing, expertise, facilities, equipment, time, and budget).

Performance Awareness and Application

Agencies must fully understand the implications of innovative practices—their ability to achieve specific performance objectives, ITS costs, benefits, risks, and challenges—in order to be able to continuously improve project or program outcomes and services through consideration of new technologies and enhanced practices. This is also a requirement for making informed decisions on evaluating and adopting specific practices. Outcomes should be aligned with established agency performance goals. Evaluating and communicating outcomes require the right performance measures, comparative data, and analytics. Tools and methodologies to benchmark, analyze benefits and costs, and ascertain and address risks and challenges all encompass indispensable aspects of understanding a practice's performance and use.

Systems, Programs, and Budgets

Essential support functions and resources are the backbone for virtually any agency activity. This is particularly true for agencies interested in innovative practices. Technical disciplines must be supported in their work with information technology, human resources, procurement and contracting, and legal functions as willing partners within their agency. From the early stages of practice exploration through deployment, supportive systems for managing information and data are essential, with significant challenges deriving from data capture, management, analysis, and utilization. Knowledge management systems should also be in place to bring together inputs from multiple disciplines and sources, and to be able to extract outputs with business value that will facilitate decision-making. Finally, advancement, especially in the PMR arena, requires sufficient resources, which means the opportunity to compete for funding within the confines of established budgetary and program processes.

Agency Culture and Organization

An agency's culture sets the tone for an environment in which innovative practices can either wither away or thrive. A supportive culture begins at the top with the agency's CEO and senior management. It includes a visible commitment to continuous improvement, receptivity to change, and innate tendencies toward collaboration and teamwork taking place within the organization. Support from internal partners across units is typically necessary to initiate and ultimately maximize the value derived from innovative practices. Organizational barriers that discourage synergies should be eliminated, or at least kept to a bare minimum, with recognized, legitimate ways to surmount them. Incentives should be in place to encourage prudent, well thought out, and managed risk justified by the probabilities and rewards of successes, with inevitable failures accepted as learning experiences rather than outcomes to be feared and avoided regardless of potential benefits.

Innovation-Supportive Staff

A function of culture and organization, and often referred to as an organization's most valuable asset, staff who embrace the tenets of advancements are mandatory to success. Staff must possess the right combination of knowledge, skills, and abilities; they must have access to new knowledge and sustain their capacities to keep up with the leading edge. Continuous education and training are essential. Staff capacity is also a consideration, however, because harnessing interest in and knowledge of innovative practices is only possible if sufficient numbers of staff are available in-house or through outsourcing. For the leader, recruitment and retention practices are geared toward proactively seeking and cultivating these staff. At the level of specific innovations, champions to drive them forward must possess a strong combination of technical expertise, passionate interest, and the ability to lead.

Legal, Regulatory, and Policy Issue Management

New products, methods, and processes require newer standards, specifications and special provisions, approval processes, and contracting mechanisms. With the accelerated emergence of digital technologies, agencies are also faced with a new set of issues relating to the use of third-party private data, digitally engineered models, electronic documentation, and commercial off-the-shelf information systems. An agency must be adept at dealing with a host of legal and regulatory issues, such as copyrights, ownership, interoperability, and liability. Agency-wide or externally imposed policies must also be examined to eliminate impediments to advance innovative practices.

External Collaboration

Advancements at transportation agencies will not occur without collaboration with external partners. Leaders and practitioners often turn to their peers, academic institutions, and the transportation industry at large to gain an appreciation for leading and best practices and to see how worthy ideas, methods, or processes can be transferred or adapted. This openness to external collaboration is essential to gain a more complete perspective on potential practices. At the same time, many innovative practices will emerge from work done in sectors outside the transportation arena and from within the private sector in general. Interaction with these communities should occur to explore applicable opportunities for technology transfer and advancement. Partnerships with the private sector are often necessary to enable appropriate sharing of knowledge, risk, and resources to cultivate and deploy such practices.

Fostering Innovative Practices Within the Organization

This guide offers transportation leaders a tool to assess their agencies' capabilities to foster innovative practices across the enterprise and identify actions to make improvements that affect culture, organization, and business practices. This tool begins with the Organization Capability Maturity Framework (CMF) to evaluate the agency's existing ability to foster these improvements and with the Organization Improvement Framework (OIF) that provides suggested strategic actions to cultivate, advance, and apply these practices across the agency.

Organization CMF

The Organization CMF assists the leader in determining the extent to which the agency is positioned to cultivate, advance, and apply innovative practices by assessing key capabilities and identifying potential gaps. Use of the Organization CMF is an internal assessment exercise based on the general process described in the next three sections.

Who Leads the Assessment?

The Organization CMF assessment can be conducted individually or collaboratively among a group of senior managers. The assessment should be considered early in the term of new leaders, and may be revisited in conjunction with updates to organization-wide strategic plans.

How Is the Assessment Conducted?

The Organization CMF assessment is a straightforward process of systematically evaluating agency-wide capabilities in terms of each of the CSFs described previously one at a time. The CSFs are numbered in a recommended order but can be assessed in any order. The user considers the criteria under each of the matrix's three levels and selects the level that most accurately describes the agency's capability. The value of the level (1, 2, or 3) is not the focus of the assessment as much as gaining an understanding of agency capability and potential gaps in capability relative to the factor's provided criteria.

For example, a user may consider all three criteria for a particular factor and decide that certain elements of Level 1 apply at the same time that certain elements of Level 2 also apply. The user may choose to characterize the agency's capability as somewhere between levels. A general characterization of the three levels is as follows:

- Level 1: The agency generally has not considered the CSF with respect to fostering innovative practices.
- Level 2: The agency has been considering the CSF with respect to fostering innovative practices, may have plans in place to develop an approach to provide the CSF capability, and may have begun to implement the approach.
- Level 3: The agency has developed an approach to provide the CSF capability and it has been largely implemented.

The assessment is complete when all seven CSFs have been evaluated. Depending on the user's preference and the context in which the evaluation was conducted (e.g., one individual vs. facilitated workshop), the assessment output should consist of a set of CSF level selections at a minimum, potentially accompanied by notes on agency strengths/advantages and weaknesses/disadvantages that substantiate the selections.

What Is the Assessment Outcome?

A key outcome of the Organization CMF assessment is to identify gaps in capability between current agency practice and a threshold target level deemed necessary to better foster innovative practices within the agency. This target level is left to the user to define precisely and should be unique to the agency and the gap in capability that has surfaced. Application of the Organization CMF does not imply that Level 3 must necessarily be achieved in all cases, but provides a general "ideal boundary" for the user to determine what a reasonable target level should be.

Following the application of the Organization CMF, a determination should be made on whether and how to address the identified gaps in capability among the CSFs. Capability maturity theory dictates a focus on the weakest of CSFs and that all are synergistically related and necessary to address (if they exhibit gaps). Senior management can determine prioritization; identification of actions to close the gaps must follow. The OIF provides a detailed set of generalized, recommended actions to pick from that should be tailored to the user's agency and augmented with implementation details.

The Organization CMF

The Organization CMF is presented in Part C, Table 19.

Part C, Table 19. The Organization CMF.

Critical Success Factor	Components	Level 1	Level 2	Level 3
1. Awareness	• Context Awareness: 　*Leading edge practices* 　*Status of R&D in progress* 　*Problems being addressed* 　*Alternative approaches being developed and tested*	• Little or no effort at an organizational level to foster interest and awareness in leading edge/innovative practices • To the extent that interest and awareness in leading edge/innovative practices exist, both are highly dependent on individual initiative among motivated staff	• Activities to foster interest in leading edge /innovative practices at an organizational level are sporadic and inconsistent • Key staff in some agency units are encouraged to keep up with leading edge/innovative practices (committees, conferences, external contacts) but such encouragement is sporadic and inconsistent, and highly dependent on individual unit managers	• Systematic, organization-wide emphasis on sustaining a high level of awareness and keen interest in leading edge/ innovative practices • Unit managers are evaluated on whether and how they encourage technical staff to stay abreast of developments in the state of the practice and innovative practices in their discipline areas
2. Performance Awareness and Application	• Alignment with Agency Performance Goals • Performance Measures • Assessment of Anticipated Benefits and Costs • Challenges and Risks	• Little or no organization-wide emphasis on the use of performance measures aligned with measurable agency goals (beyond meeting legislated or regulatory requirements) that suggest how the goals might be met through innovation • No accepted agency-wide process for benchmarking best practices or evaluating benefits and costs associated with performance-enhancing and innovative practices. When a benefit–cost assessment is done, much of it is qualitative and implicit • General, largely intuitive and subjective understanding of the challenges and risks associated with performance-enhancing and innovative practices	• Performance measurement (over and above meeting minimum requirements) to assess progress toward achieving agency goals is encouraged, but performance data are not employed regularly to improve processes on a continuing basis, benchmark best practices, or systematically relate to innovative practice potential. Where it is applied, performance measurement may motivate interest in innovative practices when shortcomings are apparent • Agency costs and benefits associated with innovation are typically quantified and analyzed, but there is no generally accepted methodology and only limited recognition of external benefits and costs • Challenges and risks associated with innovative practices are typically analyzed as a mix of intuitive and subjective assessments, as well as using some explicit, systematic risk management. However, practices for surmounting challenges and managing risks are not consistently well-defined	• Systematic performance measurement using consistent measures, definitions and data, and focused on agency-wide performance goals is an established practice throughout the organization. There is a structured, periodic, agency-wide performance evaluation process used to determine the need for enhanced practices and innovation • A systematic, agency-wide approach is taken to evaluate benefits and costs associated with innovative practices, considering factors both internal and external to the agency, and that are quantified and analyzed on a life-cycle basis • Challenges and risks associated with innovative practices are analyzed by using an explicit, systematic risk management framework that culminates in well-defined practices for surmounting challenges and managing risks

Part C, Table 19. The Organization CMF (continued).

Critical Success Factor	Components	Level 1	Level 2	Level 3
3. Emerging and Innovative PMR Practice-Supportive Systems, Programs, and Budgets	• Agency Research and Development • Agency Pilot Testing • Institutional Knowledge Management System • Access to Funding • Assistance from Support Functions (IT, HR, Procurement) • Availability of Facilities, Equipment and Test Sites	• Agency lacks robust, supportive systems and programs to foster innovative practices, including participation in applied research and development, pilot testing, knowledge management, and ability to readily access facilities, equipment, or test sites associated with the practice • Access to funding for practice is ad hoc and ill-defined and lacks an established budgetary process or program • Administrative and technical support for new initiatives and innovative practices is not readily available	• Agency has identified the need for and is attempting to develop supportive systems and programs to foster innovative practices (e.g., applied research and development, pilot testing, knowledge management, etc.) • Generally, no established budgetary process or program for funding innovative practices, but "special projects" outside of regular processes are feasible • Administrative and technical support for new initiatives is achievable, though at times requires senior management intervention	• Agency has formal program in place supported by necessary systems and functions, including sustainable applied research and development activity, processes for pilot testing including access to facilities, equipment, or test sites, and an institutional knowledge management system • Established budgetary and program processes encourage advocates of innovative practices to compete for funding • Administrative and technical support for new initiatives is readily available and provided proactively

Part C, Table 19. The Organization CMF (continued).

Critical Success Factor	Components	Level 1	Level 2	Level 3
4. Innovation-Friendly Culture and Organization	• Leadership Support • Collaboration and Teamwork • Receptivity to New Ideas • Dedication to Continuous Improvement • Organizational Barriers • Risk–Reward Response	• Little evidence of significant senior management understanding of the value of or support for innovative practices. Senior management is strongly committed to supporting existing programs using current practices and is resistant to change • Absence of a strong culture where staff are receptive to new ideas and collaboration and teamwork routinely facilitate improvements to existing practices • Organizational barriers, such as stove piped or blurred lines of unit and individual authority, strict chain-of-command or unclear lines of communication, and non-productive competitive relationships among units, inhibit innovative practices • Senior management projects a risk-averse posture toward innovation with the generally accepted notion that failure is not tolerated	• Senior management is cautiously supportive of innovative practices • Significant numbers of staff are receptive to new ideas, although this attitude varies by unit and tenure. Collaboration and teamwork toward improved practices occur in specific areas but are not yet the agency-wide norm • Organizational barriers to innovative practices are identified and addressed case-by-case, with mixed results • Agency is somewhat risk-tolerant and willing to accept the possibility of failure when pursuing innovative practices, although the negative aspects associated with failure tend to be perceived more strongly than the redeeming value of gaining learning experience	• Senior management consistently champions continuous improvement and innovative practices across agency business practices • Pervasive learning culture where staff are expected to be, and typically are, receptive to new ideas, seek technical training, and routinely collaborate on highly consequential improvements to existing practice • Systemic organizational barriers to innovative practices are minimal, two-way lines of communication are open, and the occasional challenge that arises is dealt with quickly and judiciously • Agency's robust risk management framework recognizes the potential of innovative practices' failure, readily accepts it as a learning experience, and visibly recognizes and rewards supporters of innovative practices

Part C, Table 19. The Organization CMF (continued).

Critical Success Factor	Components	Level 1	Level 2	Level 3
5. Supportive Staff	• Knowledge Acquisition and Sustainability: *Learning practices*	• Acquisition of new knowledge is typically the result of modest, incremental improvement to existing practice	• Some, but not all key staff, proactively seek opportunities to acquire and incorporate new knowledge that can significantly improve existing practice	• Staff are expected to, and the majority do, proactively seek opportunities to access new knowledge that can advance existing practice toward the leading edge
	Continuous education and training	• Support for continuous education and training that might stimulate interest in innovative practices is severely limited or unavailable	• Continuous education and training opportunities to foster innovative practices have been identified, but limited resources can make it difficult to access them	• Continuous education and training opportunities to foster innovation are treated as high priorities and readily accessible to staff
	• Staff Capacity	• Staff capacity and technical expertise is stretched thin, and committed to supporting existing programs using current practices, with little or no time to invest in leading edge/innovative practices	• Staff capacity and technical expertise needed to support innovative practices, either in-house or accessible through outsourcing, are identified and addressed in an ad hoc manner	• Sufficient staff capacity and technical expertise to support innovative practices can generally be assembled, either in-house or through outsourcing or partnering
	• Recruitment and Retention	• Recruitment and retention decisions are based on candidates' professional knowledge related to existing practices rather than areas that may support innovative practices	• New hires possessing skills and interest in leading edge practices and applying innovation are often prioritized but may be difficult to recruit	• Agency proactively seeks and cultivates staff that possess the desire and knowledge to apply leading edge/innovative practices to their roles and responsibilities; agency's reputation as an innovative institution helps to attract these individuals

Part C, Table 19. The Organization CMF (continued).

Critical Success Factor	Components	Level 1	Level 2	Level 3
6. Legal, Regulatory and Policy Issue Management	• Liability Issues • Intellectual Property Issues • Legal and Regulatory Challenges • Policy Issues	• Legal and regulatory issues that may impede innovative practices (liability, intellectual property issues, low-bid procurements) are a significant concern of agency legal staff. Resources to engage outside counsel or seek successful peer experience needed to address these problems are not available • Agency-wide or externally imposed government-wide policy level impediments (in areas such as information technology, human resources, outsourcing, and out-of-state travel) are interpreted as insurmountable barriers to advancing innovative practices	• Legal and regulatory issues associated with innovation (liability, intellectual property issues, low-bid procurements) are addressed by recourse by peer agency legal staff or outside counsel and supported by agency senior management • Agency-wide or externally imposed government-wide policy level impediments often add time and frustration to the process of advancing innovative practices, but eventually get resolved, potentially with the intervention of agency senior management	• Legal and regulatory issues associated with innovative practices are formally assessed as risks and addressed by best available legal advice, with supportive intervention from agency senior management when necessary • Policies and processes in place to advance innovative practices provide the basis to challenge, or seek special exceptions to, other potential agency or external policies that become impediments, with supportive intervention from agency senior management when necessary

Part C, Table 19. The Organization CMF (continued).

Critical Success Factor	Components	Level 1	Level 2	Level 3
7. External Collaboration	• Interaction with Transportation Agency and Academic Peers • Communication Beyond the Transportation Community • Private-Sector Outsourcing and Partnering	• Interaction with transportation agency and academic peers related to leading-edge/innovative practices is limited and based on individual interests and initiative • Exposure to leading edge practices and innovation through interaction with industry associations and technical groups is neither encouraged nor systematic • Interaction with non-transportation public agencies, private entities, or organizations/institutions where innovation is developing and there is opportunity to apply outcomes to the agency's practices, is very limited or nonexistent • Little to no consideration is given to outsourcing, sharing costs or managing risk associated with innovation by partnering with peer public agencies or the private sector	• Interaction with transportation agency and academic peers to exchange information and experience on leading-edge practices among technical staff occurs frequently but is inconsistent across agency units and disciplines • Interaction with peers and exposure to leading edge/innovative practices through industry associations and technical groups occurs sporadically, often impeded by restrictions on travel and time allocation • Interaction with non-transportation public agencies, private entities, or organizations/institutions where innovative practices are developing and there is opportunity to apply outcomes to the agency's practices, occurs occasionally but is ad hoc • Barriers to partnerships with the private-sector, supportive of innovative practices (procurement, conflict of interest, intellectual property, maintenance of competition) are limiting but are starting to be overcome in part from applicable peer experience; similar arrangements with peer public agencies are considered to share resources, risks, and experience	• Interaction with transportation agency and academic peers to exchange information and experience on leading-edge practices among technical staff is extensive and formally supported across the agency • Key staff who have a demonstrated interest and level of competency and experience are encouraged and supported to participate in industry associations and technical groups with an emphasis on tapping into leading edge/innovative practices that may apply to the agency • Interaction with non-transportation public agencies, private entities, or organizations/institutions where innovative practices are developing and there is opportunity to apply outcomes to the agency's practices takes place regularly and is formally encouraged through specially arranged exchanges of ideas and experience • Procurement, contracting, and partnership mechanisms are in place to facilitate engagement with private-sector or peer public agencies in resource and risk-sharing approaches that advance innovative practices

Organization Improvement Framework (OIF)

The OIF provides an action-oriented framework that begins with the results of the Organization CMF assessment and indicates actions required to advance the organization to the highest target level (Level 3). In identifying Level 3 as the potential target, the OIF tool recognizes improving above Level 1 but below Level 3 may be a prudent goal, depending upon circumstances, in which case the suggested actions would be scaled back to the more modest target level. In addition, while three CMF target levels have been identified for the sake of simplicity, real-world applications will indicate endless varieties of gray areas in which the digital 3-level framework may not apply so neatly.

The key to successful application of the OIF is a desire to improve along a continuum, with just how much and how far left to the circumstances and judgments inherent in each application. At a minimum, the OIF should contain for each a description of the agency's existing practices and capabilities with respect to the CSFs and their components, a description of gaps identified from the Organization CMF assessment, criteria, and performance metrics characterizing the identified target level, and actions to address the gaps and achieve the potential target (Level 3).

Part C, Table 20 presents a partial OIF illustrating the suggested actions and potential target associated with each CSF and component. These suggested actions are illustrative and are not intended to be prescriptive. In fact, coming up with customized suggested actions in a collaborative, interactive manner constitutes an invaluable step along the path to higher levels of capability.

Part C, Table 20. OIF suggested actions.

Critical Success Factor	Components	Potential Target (Level 3)	Suggested Actions
1. Awareness	• Context Awareness: *Leading edge practices* *Status of R&D in progress* *Problems being addressed* *Alternative approaches being developed and tested*	• Systematic, organization-wide emphasis on sustaining a high level of awareness and keen interest in leading edge/innovative practices • Unit managers are evaluated on whether and how they encourage technical staff to stay abreast of developments in the state of the practice and innovative practices in their discipline areas	☐ Develop a formalized program to foster staff awareness and understanding of the drivers of change and leading-edge/innovative practices, potentially incorporating the following activities: ○ Tracking and gauging the effects or influences of long-term drivers of change and resulting future scenarios, such as those identified in this guide ○ Understanding the PMR implications of the drivers and potential future scenarios ○ Gaining familiarity with essential findings from fundamental and applied R&D, what problems are being addressed, and what alternative approaches are being contemplated and tested ○ Incentivizing unit managers to encourage technical staff to stay abreast of developments in the state of the practice and innovative practices in their discipline areas ○ Participating in peer groups and regional and national forums related to innovative practices of greatest interest ☐ Initiate an internal "awareness vehicle" (e.g., website, newsletter) ☐ Establish an agency position charged with managing innovative practices and technological change, initiating efforts to explore new approaches, technologies, tools, materials, etc. and soliciting the same from others → Note: The individual in this position is recommended to lead or facilitate a number of the actions suggested in the other CSFs

Part C, Table 20. OIF suggested actions (continued).

Critical Success Factor	Components	Potential Target (Level 3)	Suggested Actions
2. Performance Awareness and Application	• Alignment with Agency Performance Goals • Performance Measures • Assessment of Anticipated Benefits and Costs • Challenges and Risks	• Systematic performance measurement using consistent measures, definitions and data, and focused on agency-wide performance goals is an established practice throughout the organization. There is a structured, periodic, agency-wide performance evaluation process used to determine the need for enhanced practices and innovation • A systematic, agency-wide approach is taken to evaluate benefits and costs associated with innovative practices, considering factors both internal and external to the agency, and that are quantified and analyzed on a life-cycle basis • Challenges and risks associated with innovative practices are analyzed by using an explicit, systematic risk management framework that culminates in well-defined practices for surmounting challenges and managing risks	☐ Initiate a systematic benchmarking exercise of agency PMR activities compared to the state-of-the-practice and articulate a performance-based vision for improvement ☐ Initiate a systematic review of agency goals with respect to state-of-the-practice performance and outcomes from PMR innovative practices and begin identifying where those outcomes can reasonably exceed existing practice ☐ Intensify and deepen overall agency commitment to the use of performance measures and benefit–cost analysis in both program design and operations ☐ Familiarize staff with case studies that demonstrate the positive impact of innovation on PMR and agency performance ☐ Establish a process where units' and individuals' recognition or rewards are related to utilization of performance measures (not necessarily the performance changes themselves) ☐ Establish a formal innovation-related risk assessment process as appropriate to PMR activities
3. Emerging/Innovative PMR Practice Supportive Systems, Programs, and Budgets	• Agency R&D • Agency Pilot Testing • Institutional Knowledge Management System • Access to Funding • Assistance from Support Functions (IT, HR, Procurement) • Availability of Facilities, Equipment, and Test Sites	• Agency has formal program in place supported by necessary systems and functions, including sustainable applied R&D activity, processes for pilot testing including access to facilities, equipment, or test sites, and an institutional knowledge management system • Established budgetary and program processes that encourage advocates of innovative practices to compete for funding • Administrative and technical support for new initiatives is readily available and provided proactively	☐ Establish an agency position charged with managing innovative practices and technological change, initiating efforts to explore new approaches, technologies, tools, materials, etc. and soliciting the same from others. Additional portfolio responsibilities can include leadership of suggested actions under this CSF ☐ Develop and institute a formal process/program to initiate and support application of innovative practices, building on the program established under Awareness ☐ Establish a development framework for the program that includes key activities within this CSF (e.g., R&D, knowledge management), oversight, and program performance review ☐ Set a budget to support the program's operation. Lead efforts to communicate the need for and to authorize organizational, administrative, or policy changes to eliminate barriers to innovative practices related to cooperation from agency support functions and systems, including IT, HR, and procurement

Part C, Table 20. OIF suggested actions (continued).

Critical Success Factor	Components	Potential Target (Level 3)	Suggested Actions
4. Culture and Organization	• Leadership Support • Collaboration and Teamwork • Receptivity to New Ideas • Dedication to Continuous Improvement • Organizational Barriers • Risk–Reward Response	• Senior management consistently champions continuous improvement across agency business practices • Pervasive learning culture where staff are expected to be, and typically are, receptive to new ideas, seeking technical training, and routinely collaborating on highly consequential improvements to existing practice • Systemic organizational barriers to innovative practices are minimal, two-way lines of communication are open, and the occasional challenge that arises is dealt with quickly and judiciously • Agency's robust risk management framework recognizes the potential of innovative practices' failure and readily accepts it as a learning experience; supporters of innovative practices are visibly recognized and rewarded	☐ Use the leadership "pulpit" to talk about, celebrate, and reward interest in and actions taken toward improvement ☐ Encourage and support education/outreach exercises among staff that share experience with innovative practices (e.g., discipline or PMR practice-focused meetings, webinars, etc.) ☐ Conduct peer-to-peer workshops with top and middle management focused on improvement successes ☐ Identify organizational barriers to fostering innovative practices potentially through practitioner staff engagement, and solicit ideas for improvement; prioritize actions to remove identified barriers to innovative practices at the enterprise level ☐ Conduct a review of the extent to which cultural attitudes foster or inhibit innovative practices throughout the agency, examining inter-unit collaboration and teamwork, receptivity to new ways of doing business, and dedication to continuous improvement and new ways to better achieve the agency's mission and goals and serve the customer ☐ Formulate and project (through media, presentations, direct communication) an enterprise attitude that encourages and expects continuous improvement applied to agency business practices, a culture of learning that embraces new ideas, and recognition that failure is sometimes inevitable but an opportunity to gain valuable experience → Note: The innovation officer can lead or facilitate the activities suggested by these actions

Part C, Table 20. OIF suggested actions (continued).

Critical Success Factor	Components	Potential Target (Level 3)	Suggested Actions
5. Staff	• Knowledge Acquisition and Sustainability: *Learning practices* *Continuous education and training* • Staff Capacity • Recruitment and Retention	• Staff are expected to, and the majority do, proactively seek opportunities to access new knowledge that can advance existing practice toward the leading edge • Continuous education and training opportunities to foster innovative practices are treated as high priorities and readily accessible to staff • Sufficient staff capacity and technical expertise to support innovative practices can generally be assembled, either in-house or through outsourcing or partnering • Agency proactively seeks and cultivates staff that possess the desire and knowledge to apply leading edge and innovative practices to their roles and responsibilities; agency's reputation as an innovative institution helps to attract these individuals	☐ Empower a designated officer to seek champions for innovative practices, internally or externally, to lead specific initiatives, both technical area-specific and PMR-practice specific; this may require reallocation of individuals' duties/availability or acquiring new staff ☐ Identify key roles necessary to support other actions taken within the OIF and develop position descriptions and target knowledge, skills and abilities ☐ Review recruitment practices, job descriptions, promotion and other career development factors for opportunities to incentivize improvement ☐ Provide support, both funding and a permitted allocation of staff time, to participate in professional capacity building activities that advance innovation knowledge ☐ Identify opportunities to connect key agency activities with appropriate university/industry/research entity units to create teams that advance specific innovative applications
6. Legal, Regulatory, and Policy Issue Management	• Liability Issues • Intellectual Property Issues • Legal and Regulatory Challenges • Policy Issues	• Legal and regulatory issues associated with innovative practices are formally assessed as risks and addressed by best available legal advice, with supportive intervention from agency senior management when necessary • Policies and practices in place to advance innovation provide the basis to challenge, or seek special exceptions to other potential agency or external policies that become impediments, with supportive intervention from agency senior management when necessary	☐ Seek support from attorneys who focus as much on "can-do" solutions as on "can't do" barriers ☐ Look at how peers have tackled similar issues ☐ Seek authority to perform trial or pilot actions that test whether and how legal, regulatory, or policy constraints can be addressed ☐ Initiate processes to modify policies, regulations, and/or statutes that unreasonably discourage or constrain opportunities for innovative practices

Part C, Table 20. OIF suggested actions (continued).

Critical Success Factor	Components	Potential Target (Level 3)	Suggested Actions
7. External Collaboration	• Interaction with Transportation Agency and Academic Peers • Communication Beyond the Transportation Community • Private-Sector Outsourcing and Partnering	• Interaction with transportation agency and academic peers to exchange information and experience on leading-edge practices among technical staff is extensive and formally supported across the agency • Key staff who have a demonstrated interest and level of competency and experience are encouraged and supported to participate in industry associations and technical groups with an emphasis on tapping into leading edge/innovative practices that may apply to the agency • Interaction with non-transportation public agencies, private entities, or organizations/institutions where innovative practices are developing and there is opportunity to apply outcomes to the agency's practices takes place regularly and is formally encouraged through specially arranged exchanges of ideas and experience • Procurement, contracting, and partnership mechanisms are in place to facilitate engagement with private-sector or peer public agencies in resource and risk-sharing approaches that advance innovative practices	☐ Building on the supportive staff, CSFs, review staff capabilities needs and develop a strategy for delineating those that are more suited (in-house or outsourced) ☐ Identify and support mechanisms for key professional staff involvement in external networks involved in innovative practices ☐ Establish a budget to support technical activities relevant to innovative practices, including travel and training ☐ Establish a forum on innovative practices with outside technical experts on a continuing basis ☐ Utilize the request for information (RFI) process to identify external innovative concepts ☐ Investigate methods of establishing increased interaction with private industry, while recognizing legal and regulatory constraints, and capitalize on available opportunities (conferences, workshops, etc.) ☐ Investigate options for public–private partnerships, including special public–private entities to manage innovative-intensive programs or projects ☐ Work within industry groups to develop methods to measure and maintain long-range research needs relevant to PMR innovative practices, periodically scan for new practices, and lead initiatives that encourage and organize collaboration and partnership to overcome barriers on a multi-peer basis

Remarks on the Practitioner's Guide to Emerging Practices

Organization CMF at the Unit Level

The OIF is geared toward assessing agency-wide capability to foster innovative practices, and can also be used by discipline leaders and technical managers to assess the same capability of fostering innovative practices at the individual unit level. Enlightened leadership at the senior management level can be dampened—indeed, undermined—by less than enlightened leadership at the middle management or first-line supervisory level. For this reason, the Organization CMF has also been included in the Practitioner's Guide as recognition that while the domains of practitioners are obviously more narrowly focused than among leaders, there is no less of a professional obligation for practitioners to ask themselves the same questions about whether and to what extent innovation is fostered in their discipline areas. Discipline and technical managers are encouraged to apply the Organization CMF to their areas of responsibility and to make a conscious choice on whether and to what degree they will accept the responsibility to foster innovation within their technical domains.

Practice CMF to Assess Specific Innovative Practice

While the principal focus of the Organization CMF is to assist leaders (and discipline and technical managers) in assessing their capability to foster innovative practices, the Practice CMF, presented in the Practitioner's Guide, may under certain circumstances be of direct use to leaders. The purpose of this CMF is to assist in determining whether a sufficient threshold of capability exists, or is within reach, to advance a specific innovative practice. With many such practices, particularly those that are more highly specialized and narrowly focused, this determination is best done at the practitioner level. However, some practices will be more crosscutting in their effects on multiple units across an agency or beyond the agency, and some may have policy and political ramifications. Others may entail strategic partnerships with sister agencies or with the private sector. In these cases, agency leadership with the purview and accountability for innovative practices with such broad-based implications may wish to take the lead in deciding whether and how to advance a specific practice. In such cases, the CMF described in the Practitioner's Guide may be of direct interest to senior managers.