



PART B

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



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Guide Orientation

This guide assists transportation professionals on the application of practices involving emerging and innovative materials, tools, approaches, and technologies to address long-range (30 to 50 years) highway infrastructure preservation, maintenance, and renewal (PMR) needs. The audience focus for this guide are the practitioners—technical or discipline managers or specialists with a direct role in highway PMR activity and performance. A companion guide focuses on agency leadership [Chief Executive Officer (CEO) and senior management] as the primary audience.

In applying this guide, the user should recognize that the future, as construed herein, extends outward 50 years and predicting it is not an easy task. Nonetheless, the guide asserts that:

- 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 to invest in innovation; and other external non-transportation-related factors.

While this guide features an in-depth examination of 16 exemplary, emerging, and innovative PMR practices worthy of familiarization and consideration for their beneficial impacts on highway PMR over this timeframe, the focus of this guide is on *preparation* rather than *prediction*. Practitioners and their agencies need to be prepared for a range of future scenarios in which highway PMR evolves and adapts, and for opportunities to capitalize on those practices that can improve agency efficiency and effectiveness and the experience of the agency's customers. Therefore, this guide is relevant to emerging PMR innovation in all forms: those highlighted in this guide, those recognizable today (those being tested and implemented or those that are still mostly theoretical), and those yet to be perceived. The guidance and the tools provided for assessment and advancement of these practices are relevant to the users today and will be to the users years from now as these practices become clearer in agencies' minds and evolve.

Finally, this guide serves as a charge to transportation agencies and professionals to advance desirable emerging PMR practices even when those practices are beyond their capability to initiate on their own. Many of these emerging PMR practices will be inherently challenging for transportation agencies to take on by themselves, particularly when they are being driven by technologies and market forces beyond their domains. This is particularly true where advanced technologies and PMR practices may emanate from sectors outside transportation, yet these outside forces 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.

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 infrastructure 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 striping, 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 functional 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 existing 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” types of work activities 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 grouting, 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 functional 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 around a roadmap for emerging and innovative PMR practices that incorporates a successive, yet iterative, series of actions: awareness, advocacy, assessment, adoption, and action plan, each of which is discussed in the sections that follow. The flow diagrams in Part B, Figures 1 through 3 illustrate how the practitioner may navigate each of these actions and access the guide's specific sections and tools.

Preparing for Emerging and Innovative PMR Practices

This section addresses awareness and advocacy of such emerging and innovative practices—knowing what the state of the practice is with respect to a given emerging PMR practice (drivers, needs, and benefits) and how to initiate efforts to seriously consider whether they should be pursued.

Awareness of emerging PMR practices begins with a recognition that the world is changing rapidly and that no institution (e.g., state departments of transportation) or institutional responsibility (highway preservation, maintenance, and renewal in this case) will be left untouched. This section begins by presenting a short “Study Background” and genesis to the research that produced this guide, which among many outcomes, posited “A Long-Range Vision” 50 years from now that articulates the future context for highway infrastructure and its characteristics and needs with respect to PMR.

The discussion then highlights important trends in “The Future Context” that have the potential to lead to the vision presented. The section also includes an “Overview of Emerging and Innovative PMR Practices and Benefits” summarizing 16 leading-edge practices prioritized by the research and worthy of consideration. These emerging practices are detailed in the Emerging and Innovative PMR Practice Database. Finally, an understanding of potential benefits and costs, both external to customers and internal to the agency, is required to enhance awareness of specific highway PMR activities and make the case for adoption on a case-by-case basis.

The PMR practice advocacy typically follows a critical threshold of awareness. It can occur both in a top-down and bottom-up manner by agency leadership as well as by practitioners. It involves communicating and cultivating knowledge gained from PMR practice awareness. Therefore, preparing for emerging and innovative PMR practices also includes perspectives on “The Importance of Leadership” and “The Importance of Practitioner Pressure.” The benefits from a certain degree of competition among peers, together with high levels of collaboration, are also discussed.

The section concludes with an introduction to seven critical success factors (CSFs) that are essential to fostering and advancing specific emerging and innovative practices and form the basis for two assessment tools. One tool helps agencies cultivate and evaluate their capabilities to advance innovative practices and to identify the actions required to assess and ultimately implement those that prove worthy into agency practice. The other tool helps agencies assess their capability and identify actions to better foster innovative practices across the agency through improvements in culture, organization, and business practices.

Emerging and Innovative PMR Practice Database

An Emerging and Innovative PMR Practice Database (provided in Part B, Appendix 2 as part of *NCHRP Web-Only Document 272*) describes 16 emerging PMR practices identified through a process of evaluation and prioritization during the research for this guide. The database helps identify (1) the anticipated impacts of specific emerging practices on seven key disciplines associated with highway PMR [pavement, structures, drainage and roadside assets, transportation systems management and operations, connected and automated vehicles (CAVs), maintenance and construction equipment, and information technology/data] and (2) the individual disciplines that will be impacted by specific practices as well as those impacts. The database allows users to build awareness for and begin assessing these PMR practices, recognizing that they are just examples of virtually limitless PMR emerging/innovative possibilities looking toward a 50-year horizon; a long list of such practices is included in Part B, Appendix 1 (available as part of *NCHRP Web-Only Document 272*).

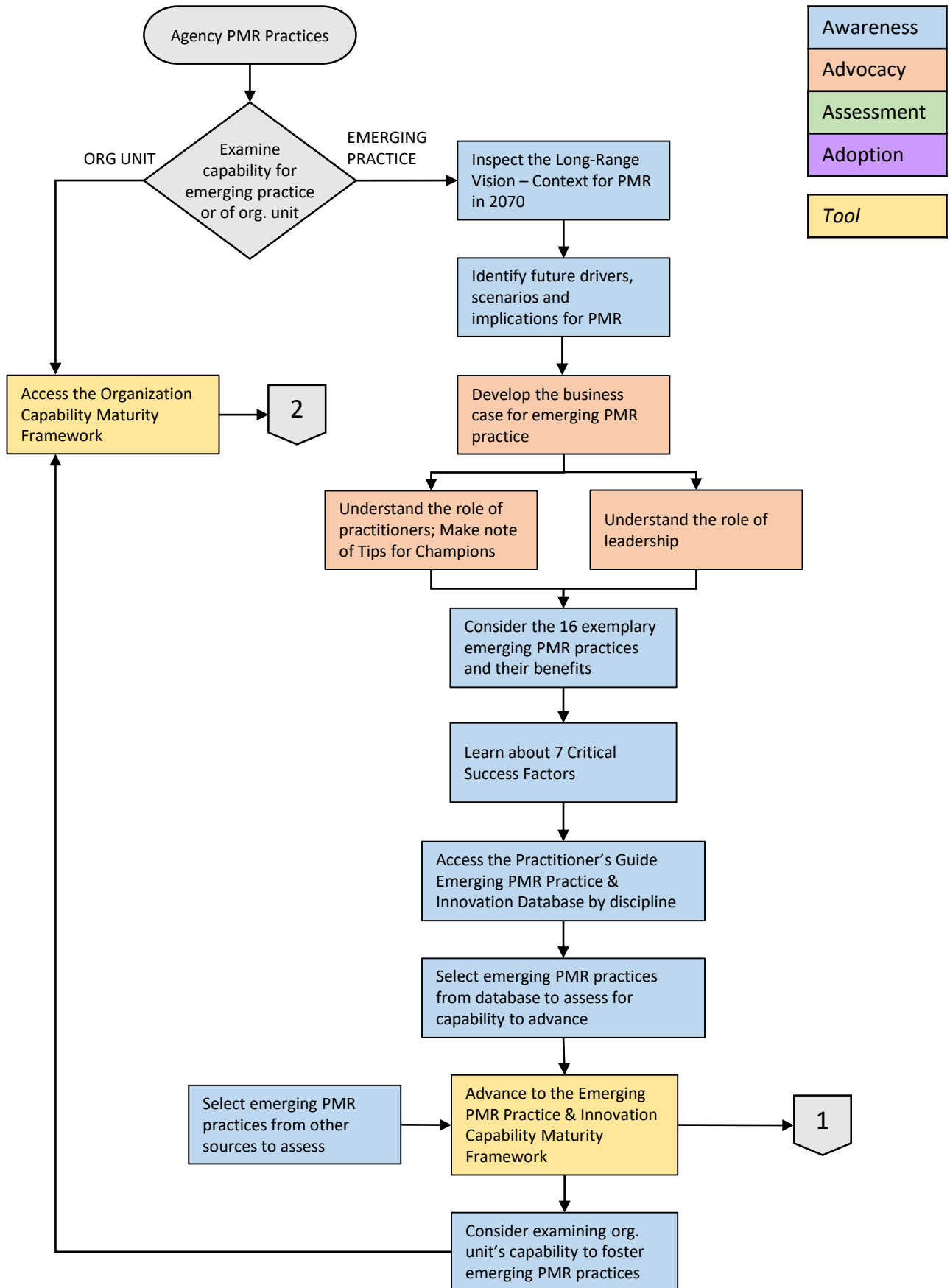
Practice Capability Assessment and Advancement

Moving beyond awareness and advocacy, agency capabilities and required actions can be assessed for those PMR practices worthy of investigation. The goal of such an assessment is to determine if the agency, unit, or discipline possesses sufficient capability across the seven CSFs to evaluate and potentially adopt the practice, and what key action steps would be necessary. This section of the guide provides a set of frameworks to accomplish this task.

The Practice Capability Maturity Framework (CMF) provides a straightforward, criteria-based structure to evaluate the competency to advance a specific emerging PMR practice. Should the application of the CMF indicate a threshold of capability sufficient to consider advancing a specific innovation, a Required Actions Framework (RAF) would then lay out steps for advancing the practice. These steps are intended to fill essential gaps in capability identified through the CMF assessment, initially considering benefits and costs, and laying out a high-level plan for moving ahead. The combination of the CMF and the RAF should provide the essential information for making a go/no-go decision on whether to commit to advancing the practice—moving from adoption to action. Both the CMF and RAF are supplemented by illustrative examples drawing upon PMR practices identified in the database.

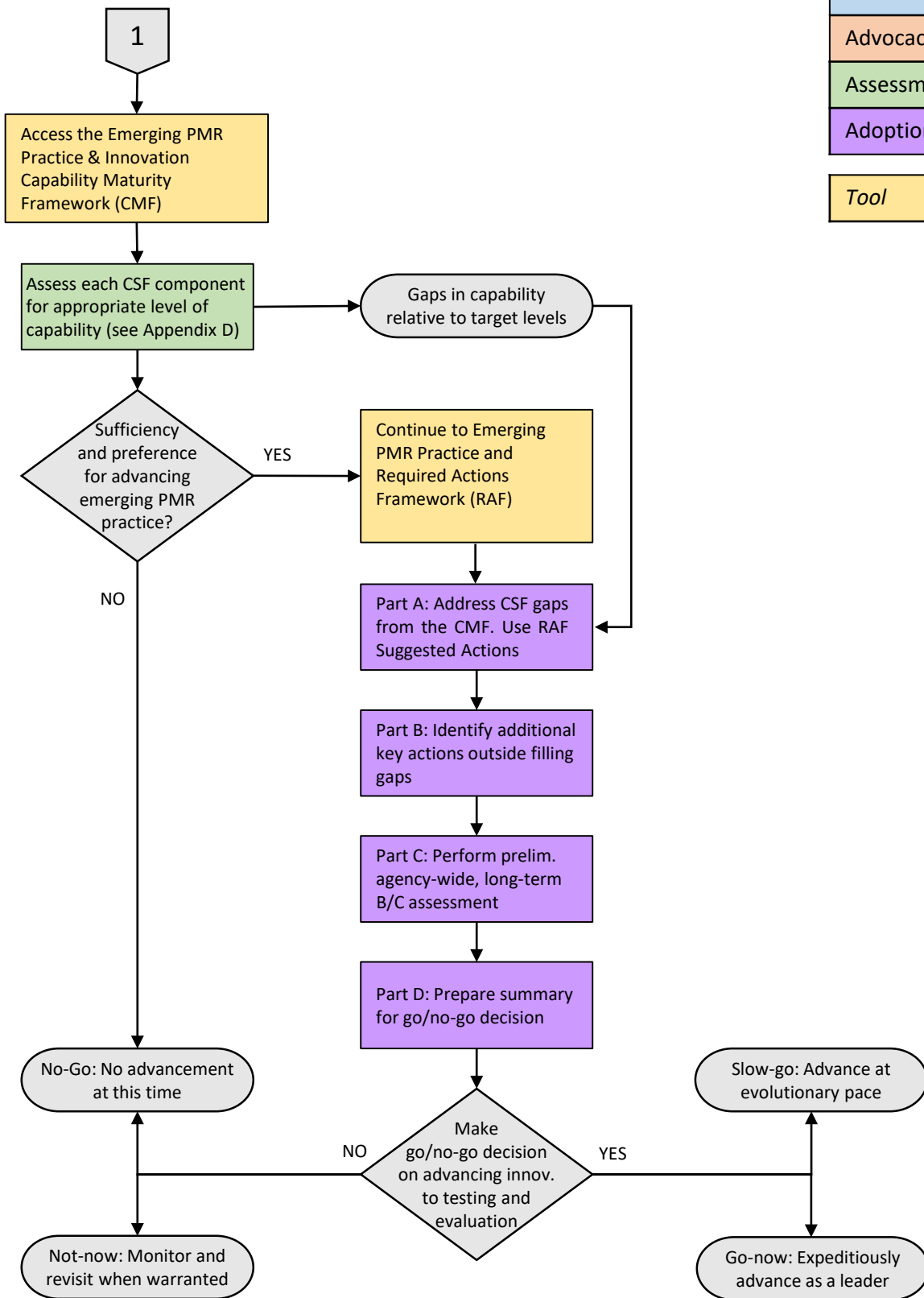
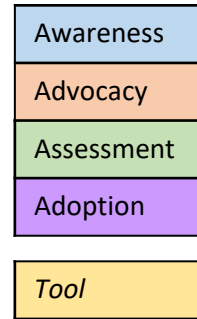
Fostering Innovation Within the Agency

This section presents frameworks focused on fostering innovative practices: the Organization CMF and the organization improvement framework (OIF). Their intent is to examine general capabilities at any level of the organization, ranging from the enterprise as a whole to individual units within the agency, to foster innovative practices by drawing upon the same seven CSFs used in assessing specific innovative capabilities.

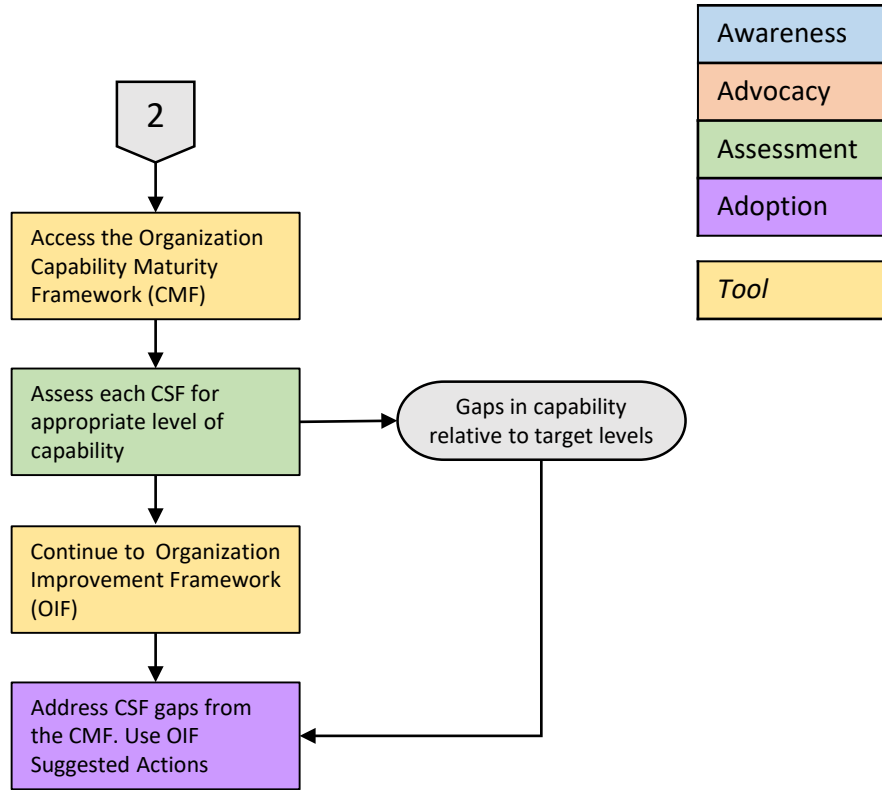


Awareness
Advocacy
Assessment
Adoption
Tool

Part B, Figure 1. How to use the practitioner's guide (1 of 3).



Part B, Figure 2. How to use the practitioner's guide (2 of 3) (B/C = benefit-cost). (Appendix D is available as part of NCHRP Web-Only Document 272.)



Part B, Figure 3. How to use the practitioner's guide (3 of 3).

Preparing for Emerging and Innovative PMR Practices

Background

This guide is prepared under the NCHRP Project 20-83(03)A, “Long-Range Strategic Issues Affecting Preservation, Maintenance, and Renewal of Highway Infrastructure” that addresses long-range strategic issues (30 to 50 years into the future) that will likely affect transportation organizations. This project is one of seven separate 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 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 list of more than 60 potential emerging 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 explicit criteria that included the following:
 - Responsiveness to future context,
 - Departure from current practice,
 - Degree of impact, and
 - Plausibility.
- Condensing the practices into 16 emerging practices (in consultation with a group of transportation agency and industry professionals).
- Assessment of the benefits of embracing these emerging PMR practices when considered in the context of a vision for the nation’s future highway network (in 2070).

This guide begins with a long-range vision for PMR (50 years into the future) to set the context for how PMR activities will play a vital role and how transportation agencies should think strategically and tactically to embrace and advance emerging and leading-edge PMR 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. This network will continue to include pavements, bridges, tunnels, drainage systems, and other components of highway infrastructure that are familiar in today's world and will remain familiar in the evolving context. 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—necessary to investigate and implement beneficial emerging 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), nor is it necessary. Rather, the implications of these drivers and scenarios help inform what emerging practices may be most beneficial to address the implied challenges and risks agencies will face as they navigate an evolving and uncertain future.

Part B, Table 1 provides a 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 PMR needs in a concerted effort to stay ahead of the curve and proactively seek opportunities to apply responsive emerging practices.

Part B, 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

This guide highlights a select group of 16 emerging PMR-related practices that best addresses the implications of identified future drivers and scenarios (briefly summarized later in this guide). The next section introduces the Emerging and Innovative PMR Practice Database (provided as Part B, Appendix 2 in *NCHRP Web-Only Document 272*) that presents detailed information on each of the 16 practices from the perspectives of seven technical disciplines. These practices, however, do not form a definitive list on which transportation agencies should solely focus as other emerging/innovative practices may be encountered over the decades to come. The guide contemplates a broad range of future drivers and scenarios and focuses on their implications to PMR-specific activities, which will inevitably evolve over a 30- to 50-year timeframe. The guide further posits that a deliberate focus on specific emerging PMR practice will reap dividends for transportation agencies when considering the ramifications of future change in the VHN and drivers of change.

Making the Case for Emerging and Innovative Practices

While there is a certain qualitative “feel-good” benefit that may accompany doing something that is new and different, 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 in general, but there are unique reasons for advancing emerging PMR practices that agency leaders and practitioners need 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 that:
 - 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? 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 result from practices 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 assessing the benefits of these practices, particularly those requiring upfront outlays in expectation of downstream benefits.

PMR Innovative Practices 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 practices. At the same time, actively encouraging the exploration of innovative 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 will improve the likelihood that PMR efforts will continue to attract the necessary talent and potential champions.

PMR Innovative Practices Are Pathways to Opportunities

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 that are largely derivative of more directly measurable performance goals such as safety, mobility, access, reliability, and resilience. Because PMR activities affect all of these areas, 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 the 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 innovation. Those organizations that have kept up with the leading edges of innovation 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 emerging 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. While this guide is focused on practitioners, it is important for them to appreciate what might be expected of their agency's leadership in the advancement of emerging and innovative practices. This becomes especially important in considering what actions practitioners might take to stimulate interest among agency leaders in emerging and innovative practices that deserve their attention and support.

For the purposes of this guide, those considered to be in leadership positions include not only the CEO, but also senior managers who have a seat at the table as decisions are made and 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.

Because supportive leadership characteristics for PMR innovative practices cannot be separated from other areas, they are addressed in broader terms recognizing that sometimes PMR functions receive less leadership attention than other higher profile areas.

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 PMR of the physical plant. These are all too frequently viewed as routine and mundane in the absence of pressing issues, and therefore less prominent on the leadership radar screen—except when erstwhile low-key PMR issues lead to major problems, such as an unplanned system closure resulting from inadequate attention over time.

Innovative and emerging PMR practices may require a special effort to ensure that they assume 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 consequences that can result from “under-engaging” in PMR issues. Leaders would do well to ensure that PMR and the opportunities for practices that raise the bar do not become a leadership blind spot.

How Important Is Front-Office Engagement?

It is possible for emerging/innovative practices to occur in organizations in the absence of active leadership support, though not as likely. 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 such practices to flourish in an organization, leadership must be onboard, whether through highly visible and encouraging actions or through less visible but no less important support. Innovative practices must not only be encouraged and supported, but also 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.

External Communication

In addition to instilling and sustaining an environment for innovative practices 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 should continuously and consistently educate these external audiences on the benefits and progress (or failures) of these practices. Successful communication requires framing the proposed innovative practices 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 a specific practice is often viewed more in the domain of the practitioner, leaders are in the best position to facilitate a multidiscipline, interoffice systems 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 who 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 follow the status quo, 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. As they may not possess a background steeped in the technical specifics of PMR, 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.

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 practices are likely to be greater. The implicit assumption is that few, if any, agencies become leaders of innovative practices across all functions. Rather, those that strive to be in the forefront of innovative practices 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 innovation strategy is to learn and adapt from the experiences among pioneering peers, or as in some cases from developments led by industry (such as CAVs 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. Not starting 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 (not usually a comfortable position for leaders to explain) or rushing into or reacting to a practice for which the agency may be ill-prepared.

The hesitancy or inability to get started may be due to the short-term thinking of agency top-level leadership, which tends to turn over relatively frequently. It is asking a leader to rise above understandable instincts to focus primarily on short-term problems and to invest energy and resources toward innovations whose benefits in years to come they may be unlikely to experience. Another constraint that may dampen interest in innovations over the long run stems from the process—and the politics—of annual budgeting and the “not-essential-on-my-watch” 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 emerging and innovative practices may ultimately result in cost savings and service improvements to the benefit of public-sector agencies and the customers they serve. However, they may have certain short-run or long-term negative impacts on some individuals or groups who have a vested interest in the status quo and who may therefore use every tool at their disposal to steer a highway agency away from implementing 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 practices, but it reflects a reality that often needs to be addressed.

Change Management

It is also important for agencies to consider the need to change management strategies to help implement innovative practices. The potential for resistance to change from legacy systems and practices, particularly among practitioners whose skillsets may no longer be needed and from managers whose area of responsibility may be diminished, should not be ignored. An essential aspect of this change 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 the investment of funding as well as the investment of time and energy, which can be scarce when dealing with barriers to change.

The Importance of Practitioner Pressure

Seasoned practitioners who specialize in technical disciplines know that advancing the state-of-the-practice toward the leading edge requires not only technical expertise but also a proactive approach that results in upward pressure on leadership to invest in innovative practices. This is particularly true for PMR-related activities where opportunities for innovation are often 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 new ways of doing business, there will be a bottom-up pressure that complements top-down agency leadership to encourage innovative practices. The most daunting challenge for practitioners lies in advocating for emerging and innovative practices in an organization whose leadership and culture fall 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, innovation can occur even in an organizational culture somewhat indifferent to fostering innovation. Without practitioner champions, no amount of top-down initiative can force innovation.

Innovation Champions

While the major waypoints on the road to PMR innovation 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 are typically 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 practice.

Just as leaders must build trust with external stakeholders by communicating the benefits and progress (or failures) of 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, 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; two or more co-champions is also a possibility. There is strength in numbers, but ultimately it becomes important for one person to become the first 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.

Part B, Table 2 presents a list of "Tips for Emerging and Innovative PMR Practice Champions" in the form of questions practitioners must ask themselves as they deploy strategies to inform and convince leadership of the value and benefit of such practices to help win support for their pursuit. Leadership will want to know how to implement these practices, not just why. Framing the argument (making the case), incorporating input from appropriate parties, and anticipating and preparing for questions from leadership are all critical considerations.

Part B, Table 2. Tips for emerging and innovative PMR practice champions.

- Look for improved/innovative opportunities that arouse your curiosity:
 - What are your agency's "beyond the leading-edge" practices and opportunities?
 - Does your experience and interest align with those opportunities?
- Become *the* expert in that emerging or innovative practice and what it can do for your agency:
 - Where is the leading edge?
 - What has been their experience?
 - What is the state of the practice in your agency? Among peers?
- Prepare an agency needs assessment and reality check (invite colleagues to critique):
 - How real is the opportunity?
 - How high is the priority?
 - Are the benefits likely to outweigh the costs?
 - Are there any insurmountable barriers?
- Conduct a personal interest assessment:
 - How enthused am I about this specific emerging or innovative practice?
 - Am I willing to be a champion?
 - Is there someone better suited and interested?
- Prepare a capability assessment [complete the capability maturity framework (CMF)]:
 - What are the critical success factors (CSFs)?
 - Do we have threshold capability to advance this practice?
 - What are the capability gaps that must be addressed?
- Develop an action plan [complete the required actions framework (RAF)]:
 - What action steps are needed for threshold capability?
 - With whom do we need to collaborate?
 - What are the barriers, risks, and strategies to address them?
 - What other actions are needed?
- Perform a benefit–cost analysis and determine whether to recommend
 - Do we have a good estimate of costs (including significant contingency)?
 - Have we identified and monetized benefits?
 - Is it clear that benefits outweigh costs?
 - Is it clear that this practice should be advanced?
- Line up support with peers
 - Have we identified units affected or whose support is needed?
 - Have we done all we can to bring them on board?
- Present the Case—Practitioners to Leaders
 - Are we convinced? Are we energized?
 - Do we know who will impact the decision and address their likely concerns?
 - Do we know who will make the decision and address their likely questions?
 - Have we boiled down the pros and cons to bare essentials?
 - Have we defined all options for whether and how to proceed?
 - Have we prepared a compelling case?
 - Are we ready for a "Round Two" if "Round One" falls short?

Peer Agency Pressure and the Opportunities Presented

State transportation agencies enjoy a longstanding tradition of particularly close inter-relationships 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 emerging PMR practices and for collaboration in advancing these innovations. 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, 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 practices being advanced among peer transportation agencies and determining potential relevance and value added on the home turf.
- Soliciting peer agency experience with specific PMR practices to obtain objective feedback and to temper less-than-objective claims from innovation advocates or critics.
- Providing “ammunition” in advocating advancement of an emerging 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 innovative PMR practices.

Overview of Emerging and Innovative PMR Practices and Benefits

Part B, Tables 3 through 18 below provide brief summaries of the 16 emerging PMR practices identified through a process of evaluation and prioritization during the research for this guide. The summaries focus on what each 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. These tables are followed by a general summary of their anticipated benefits. The following section introduces the Emerging and Innovative PMR Practice Database that explores these practices in much greater detail and organizes them by PMR technical discipline.

Part B, Table 3. Hyper-performance materials.

Emerging PMR Practice	Hyper-Performance Materials
Infrastructure Disciplines Covered	Pavements, Bridges, Tunnels, Ancillary Assets
Description	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Incremental advancement for an agency • Breakthroughs currently in exploratory research and development stages

Part B, 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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 B, Table 5. Perpetual/long-life highway infrastructure.

Emerging PMR Practice	Perpetual/Long-Life Highway Infrastructure
Infrastructure Disciplines Covered	Pavements, Bridges, Tunnels
Description	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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 B, 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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 B, 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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 B, 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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 B, 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Significant improvement to a highway agency • Much is known from application to online retailing, genetics, finance, health informatics

Part B, 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Next generation advancement in maintenance practices • Linked to advancements in IT, geomatics, and geophysical systems and sensor technologies for highway condition assessment

Part B, 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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 B, Table 12. Structural health monitoring.

Emerging PMR Practice	Structural Health Monitoring
Infrastructure Disciplines Covered	Pavements, Bridges, Tunnels, Asset Management
Description	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • A radical advancement for highway agencies • More research and pilot studies are required • At least one deployment currently under experiment (United Kingdom)

Part B, Table 13. Construction robotics.

Emerging PMR Practice	Construction Robotics
Infrastructure Disciplines Covered	Pavements, Bridges, Tunnels, Ancillary Assets
Description	<ul style="list-style-type: none"> • Advanced form of automation that focuses on mechanizing construction processes with no or little human intervention
Strategic Value	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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 B, Table 14. Artificial intelligence—PMR traffic management applications.

Emerging PMR Practice	Artificial Intelligence—PMR Traffic Management Applications
Infrastructure Disciplines Covered	ITS Equipment, TSMO
Description	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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 B, Table 15. Enterprise information systems—PMR applications.

Emerging PMR Practice	Enterprise Information Systems—PMR Applications
Infrastructure Disciplines Covered	Pavement, Structures, Ancillary Assets, TSMO
Description	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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 B, 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Radical emerging PMR practice for a highway agency • Many barriers and intermediate steps • Culmination of other emerging PMR practices (many mentioned elsewhere)

Part B, 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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 B, 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Currently emerging organically, but a radical advancement • Technical and business perspective challenges related to legacy processes, inadequate data acquisition infrastructure, standards and protocols, security

External Benefits from Adopting Emerging PMR Practices

The benefits of emerging and innovative PMR practices are ultimately for the people and enterprises served by the transportation agency. It is generally accepted, but still not universal practice, to explicitly account for benefits beyond the agency's "internal" bottom line in making investment decisions. Therefore, this guide explicitly accounts for these external benefits in making a fair and complete determination of whether and to what extent a specific practice should be advanced.

External benefits (i.e., benefits to customers) are categorized into five interrelated areas: improved safety, improved customer satisfaction, improved resiliency, reduced congestion, improved system reliability, and greater environmental sustainability.

Improved Safety

Emerging PMR practice impacts on safety stem from reduced exposure to substandard asset conditions and reduced frequency and duration of work zones, improved work zone enforcement, and the results of improved traffic flow stemming from advanced TSMO capabilities. As highway assets and vehicles become more connected, there is significant potential to share information in real time, which can be used to inform cars and drivers of work zones, upcoming traffic, or other vehicles. Indirect impacts on safety will be derived from the emerging PMR practices that improve the collection, analysis, and application of data, and improve program design and asset management, all of which contribute to safer operations.

Improved Customer Satisfaction

Improved customer satisfaction is a compelling benefit of several of the emerging PMR practices. Transportation agencies exist to serve the transportation needs of customers, whether they are using, or less directly benefitting from, the service provided. Advancements in PMR that reduce disruptions and improve reliability and comfort enhance customer experience. They improve the perception in the eyes of the customer (taxpayer) of the value the transportation agency provides for the resources they use.

Improved Resiliency

The urgent need for transportation resiliency is only recently becoming fully understood and is not likely to subside in the decades to come. Whether from changes in climate, extreme weather, geologic forces, or manmade, the threats to the physical integrity and operational capability of highway infrastructure are real and consequential. Emerging PMR practices that strengthen and respond to the PMR needs of the physical elements of the system are a major factor in improving the resiliency of highway infrastructure.

Improved Traffic Flow

PMR innovative practices contribute to improved flow insofar as they reduce the need for disruptive PMR activities and provide improved communication on real-time conditions to vehicles and drivers. Communication between vehicles and automation can reduce slowdowns caused by merges, weaving, and rubbernecking. Communication from the highway asset to vehicles can dictate a safe and more uniform operating speed. By limiting reliance on human judgment, more analytically based and objectively informed decisions can be made to ensure that traffic continues to flow at a speed dependent on the traffic situation and on the condition of the asset.

Improved System Reliability

Reliability is increasingly important in travel decisions as unanticipated delays cannot be planned for without allowing for significantly greater travel times than may have been necessary. Many of the same improved life-cycle and TSMO-related PMR innovations that contribute to safety and mobility also contribute to improved reliability. Both improved asset condition and state of good repair improve asset reliability since assets will fail less frequently. Advancements in remote sensing or connected vehicles can report maintenance or repair needs of a highway asset sooner than a routinely timed inspection.

Environmental Sustainability

Some PMR practices will emerge to address environmental sustainability goals. These practices will often relate to the materials used to create and recycle assets or to new ways to maintain assets and will have direct sustainability benefits. Indirect benefits can also be achieved through emerging practices that improve the lifespan of an asset and innovations that minimize maintenance needs. Delaying the replacement of assets and decreasing the amount of maintenance required can conserve resources and avoid additional pollution spent by work crews accessing repair sites. Other indirect benefits can be achieved through improved traffic operations. With increased mobility and reliability, vehicles can travel at higher speeds and can spend less time sitting in traffic, thereby preventing additional vehicle emissions. In addition, efforts to decrease asset replacement and maintenance needs mean that less capital and operations and maintenance costs are needed over the life-cycle of the asset. For a highway agency, this supports program sustainability as agencies can do more to maintain the asset with less money, while for users, it means that their tax dollars are being used more effectively.

Internal Benefits of Emerging PMR Practices

Categorizing some PMR practice benefits as “internal” is a bit artificial in the sense that the public (whether as taxpayers or customers or voters) are the real beneficiaries. As noted earlier, a complete assessment of innovation benefits must extend beyond the narrowest purview of agency responsibilities. However, the reality is that limited budgets may constrain the ability of agencies to implement emerging practices that may be cost beneficial on the basis of customer benefits that do not show up in agency coffers. These agencies may be constrained to consider PMR practices on the basis of benefits to their internal bottom lines. The following internal benefits are clearly interrelated and to some extent, overlap.

Improved Asset Performance

Emerging PMR practices offer benefits that improve highway infrastructure performance. Such benefits support the efforts of highway agencies to achieve performance targets. Infrastructure that is performing within a relatively narrow range of acceptable performance levels through improved sensing of real-time conditions and rapid responses will generally require fewer resources over the long run than assets that fluctuate significantly in condition and where less frequent but more intrusive PMR activity may be required to restore a more deteriorated element to acceptable condition. The reduction in PMR activity to bring the asset into a state of good repair will decrease the cost and effort associated with improving the state of the asset. This is the most significant internal benefit of emerging PMR practices.

Improved Performance Measurement and Asset Data Utilization

Emerging practices that improve the life cycle of PMR assets through adoption of a long-life approach—supported by asset and operational performance monitoring systems as well as complementary data utilization and analytics—have the most consequential impacts on the core agency objectives of improved efficiency and effectiveness. These practices are supported by a set of processes, techniques, and methodologies that are heavily dependent on developments in sensor technologies, embedded systems, network connectivity, data management, data analytics, and automation that individually, and to an even greater extent in combination, contribute to improving agency performance. The improved data acquisition and utilization can assist agencies in making better PMR resource allocation decisions resulting in longer useful life, fewer and shorter road closures for PMR actions, and improved agency efficiency and effectiveness.

Lower Capital and Life-Cycle Costs

Emerging PMR practices should generally allow highway agencies to save money on the annual costs associated with the operations and maintenance of their assets as well as on periodic capital investments to extend the useful life of an asset. The challenge, as indicated in other sections of this guide, is to muster the will and defend the decision to make a significant initial investment from a constrained annual budget in expectation of downstream savings.

Improved Organizational Processes and Efficiencies

Capitalizing on many of the innovative advancements may require significant changes in agency business and technical processes. For example, deciding to pursue certain innovations may reveal weaknesses or gaps in agency business processes, information technologies, decision-support and knowledge management systems, procurement practices and limitations, and workforce recruitment and training (just to mention a few areas).

Improved PMR Delivery

It is not surprising that improved PMR activity delivery in terms of cost, schedule, and quality (and incentive to innovate) is closely related to private-sector interest and competition in areas supportive of improved PMR. Many emerging PMR practices are driven by private-sector interests and innovations in non-transportation sectors, including materials (e.g., green chemistry), production (e.g., 3D printing), methods (e.g., robotics), information (e.g., artificial intelligence), and communications (e.g., V2I). An agency that demonstrates its interest in and a track record for advancing innovative practices will attract greater private-sector interest and benefit from improved competition.

Critical Success Factors (CSFs)

Inertial responses to change among individuals and within organizations are common and must be anticipated for innovative practices to occur. It is therefore only realistic to expect that instilling a pervasive and persistent desire to foster and welcome such 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 these 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 PMR practices.

What It Takes to Succeed

Success can be defined as overcoming challenges and risks to fostering innovation and adopting specific emerging PMR practices that provide defined benefits. The challenges and risks associated with innovative 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 innovative practices among (and within) organizations a challenge requiring customized strategies and processes to educate, encourage, convince, demonstrate, and deploy these practices.

External Factors: Myriad external factors, such as market uncertainties and government regulations, influence the acceptance and implementation of innovative practices among highway organizations. Many of these 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 the 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 program development
- **Agency Institutional Context:** Relates to internal agency culture, organization, and staff willing and capable of capitalizing on such practices
- **External Collaboration:** Involves interaction and collaboration with key communities outside the agency and partnerships with the public- and private-sector to support innovative practices

This guide defines seven CSFs across these categories where challenges and risk must be considered in advancing emerging/innovative practices. These factors form the basis for evaluating and improving agency capability to advance specific PMR innovative practices and to foster innovation (discussed in the next sections).

Awareness of Emerging PMR Practices

Awareness of emerging PMR practices refers to how in-tune an agency, unit, or individual is with the state-of-the-art, trends in innovation areas, and where the agency, unit, or individual is

within their practice. Awareness can refer to the context in which these practices apply, 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 emerging 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 a given emerging practice—its 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 emerging practices. Outcomes from embracing emerging innovation 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 are all indispensable aspects of performance understanding and use.

Supportive 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 continuous improvement. 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 emerging 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, the advancement of a given emerging practice, especially in the often less-visible arena of PMR, requires sufficient resources, which means the opportunity to compete for funding within the confines of established budgetary and program processes.

Innovation Friendly Culture and Organization

An agency's culture sets the tone for an environment in which innovative practices can either wither away or thrive. A culture supportive of innovative practices 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 to maximize the value derived from these 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.

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 innovative practices 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 these 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 practices, 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

The introduction of innovative practices 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 transferable or adapted. This openness to external collaboration is essential to gain a more complete perspective on potential innovations. At the same time, many 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 innovation. Partnerships with the private sector are often necessary to enable appropriate sharing of knowledge, risk, and resources to cultivate and deploy innovation.

Emerging and Innovative PMR Practice Database

Part B, Appendix 2 (available as part of *NCHRP Web-Only Document 272*) contains the Emerging and Innovative PMR Practice Database. This tabular database describes 16 significant emerging PMR practices, organized by seven key discipline areas associated with highway PMR. The seven disciplines are pavement, structures, drainage and roadside assets, transportation systems management and operations, CAVs, maintenance and construction equipment, and information technology/data. The database permits the user to focus either by discipline or by innovation across disciplines to access information on what each practice is and does; what anticipated future needs it best responds to; what the anticipated applications are for preservation, maintenance, and renewal activities; what benefits are expected; and what challenges to implementation are likely to be encountered. A detailed review of the material in the database permits the user to initiate a discipline-specific awareness of this select group of exemplary emerging PMR practices.

PMR Practice Capability Assessment and Advancement

This guide offers the practitioner two assessment tools based on applications of the capability maturity framework (CMF). The first relates to the evaluation of a particular emerging PMR practice in question (Practice CMF) and the second relates to the agency's ability to foster such practices in general (Organization CMF). This section addresses the former, and the following section addresses the latter.

Since the principal focus of practitioners is likely to be on considering PMR-related practices within a specific discipline or disciplines, their primary interest would lie in assessing capability with respect to a particular practice, such as those included in the database. Therefore, the Practice CMF is the assessment tool the practitioner is expected to use more regularly. Nonetheless, this guide recognizes that, just as leadership must do at a broader enterprise level, fostering innovative practices within a particular unit or discipline is equally important to being able to assess and advance PMR practices. Indeed, the practitioner is likely to be called upon to identify, and be required to support, organizational-level improvements necessary to advance PMR practices.

Within this section and the next, each capability assessment tool is paired with a follow-on framework—the RAF—to assist in making decisions on next steps. This RAF coupled with the Practice CMF provides a template for creating a high-level action plan for determining whether and how to advance the practice.

The organization improvement framework (OIF) presented in the next section follows the Organization CMF, providing suggested strategic actions to cultivate, advance, and apply innovative practices within the agency, unit, or discipline.

Practice CMF

The Practice CMF assists the practitioner in determining the extent to which the agency, unit, or discipline is positioned to seriously evaluate and potentially adopt an emerging PMR practice in question by assessing key capabilities and identifying potential gaps. Use of the Practice CMF is an internal assessment exercise based on the general process described in the next three sections. Part B, Appendix 3 (available as part of *NCHRP Web-Only Document 272*) contains additional background on the concept of capability maturity.

Who Leads the Assessment?

The Practice CMF assessment can be conducted individually by an interested staff person, ideally one who is inclined to be an “innovation champion” (e.g., the manager or a staff member of a key agency unit responsible for highway PMR) or collaboratively by a group of motivated managers and staff. A collaborative exercise may also include participation from support functions such as human resources, legal, and information technology.

How Is the Assessment Conducted?

The Practice CMF assessment is a straightforward process of systematically evaluating the emerging PMR practice-specific capabilities in terms of each CSF one at a time. These factors are numbered in a recommended order but can be assessed in any order that suits the user. The user considers the criteria under each of the matrix's three levels and selects the level that most accurately describes the agency, unit, or discipline's capability relative to the innovation in question. 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 CSF criteria provided. For example, a user may consider all three criteria for a particular CSF and decide that certain elements of Level 1 and Level 2 apply at the same time, and 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 is in a relatively weak position to advance the innovative practice, with significant gaps in capability.
- Level 2: The agency is in a potentially tenable position to advance the innovative practice, but should address some gaps in capability that could pose risks to a successful implementation.
- Level 3: The agency is well positioned to advance the innovative practice.

The assessment is complete when all components of the seven CSFs have been evaluated. Depending on the user's preference and the context in which the evaluation was conducted (e.g., one individual versus 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 Practice CMF assessment is to identify gaps in capability between current agency practice and a threshold target level deemed necessary to advance the PMR practice under consideration. This target level is left to the user to define precisely and should be unique to the agency, the specific practice, and address the gap in capability that has surfaced. Application of the Practice 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 the reasonable target level for a specific practice. Following this assessment, a determination should be made as to whether there is (1) a critical mass of capability existing or achievable in a reasonable timeframe to consider advancing the specific PMR practice and (2) a desire to advance the practice.

If there is receptivity in advancing a particular practice, it will be important to systematically define the key steps necessary to address significant gaps in capability that may have been revealed by the assessment. These steps would also need to be integrated with all other significant actions that will be required to incorporate the emerging PMR practice into the agency, unit, or discipline's work program and advance it through applied research and development, evaluation, testing, and demonstration (as applicable).

The Practice CMF

The Practice CMF is presented in Part B, Table 19; an example to illustrate application of the process and the potential outcome of the assessment is provided in Part B, Appendix 4 (available as part of *NCHRP Web-Only Document 272*). The example uses the application of calcium sulfoaluminate (CSA) cement, a variety of hyper-performance material, to pavement PMR activities. For each component of the CSFs, a hypothetical evaluation provides the kind of determination a user is encouraged to make for each factor component. The example depicts a mix of levels (1, 2, or 3, indicated by shading) to further represent a realistic assessment outcome. The actual CMF assessment result will naturally depend on the user agency, unit, or discipline's context and the practice under review.

Part B, Table 19. PMR Practice CMF.

Critical Success Factor	Component	Level 1	Level 2	Level 3
1. Awareness of the Emerging PMR Practice	<p>Context Awareness: <i>Leading edge practices; Status of R&D in progress; Problems being addressed; Alternative approaches being developed and tested</i></p> <p>Specific Awareness: <i>What it is; What it does; Where it should work well; Where it might not apply; Level of effort and resources required (staffing, expertise, facilities, equipment, time and budget)</i></p>	<p>Largely unaware or very limited awareness and interest</p> <p>Largely unaware of the specific practice</p>	<p>Some awareness and moderate interest in following the fundamental and applied research and development</p> <p>Have some awareness of the practice and experience among early adopters</p>	<p>High level of awareness and keen interest in closely following fundamental and applied research and development in this area</p> <p>Have been closely tracking the emerging practice and experiences in the testing and trials among early adopters</p>
2. Performance Awareness and Application	<p>Alignment with Agency Performance Goals</p> <p>Performance Measures</p> <p>Assessment of Anticipated Benefits and Costs</p> <p>Challenges and Risks</p>	<p>Although potentially beneficial, it is unclear if the PMR practice addresses a priority problem of the agency</p> <p>Aware of performance goals associated with the PMR practice, but little or no history or experience with applicable performance measures and measurement practices</p> <p>Agency benefits and costs are at least qualitatively identified with a reasonable level of certainty, and focus on outputs rather than outcomes</p> <p>There is a general, largely intuitive and subjective understanding of the challenges and risks in applying such PMR practice but they are not well organized or presented</p>	<p>The practice addresses a recognized problem and an inferred, though not explicitly defined, performance goal of the agency</p> <p>Able to relate performance goals associated with the PMR practice to specific performance measures, use data on existing practice as a baseline, and establish measurement practices that can evaluate its performance</p> <p>Agency benefits and costs are quantified and analyzed. Outputs are measured and related to inputs required and outcomes are defined. Limited recognition of external benefits and costs</p> <p>Challenges and risks in applying such practices are identified in a mix of intuitive and subjective assessments as well as some explicit, systematic risk management, but strategies for surmounting challenges and managing risks are general and not consistently well-defined</p>	<p>The practice addresses a significant problem and an explicit performance goal of the agency</p> <p>Full capacity to access historic performance data and apply measurement practices to define, apply, and communicate performance measures that characterize the performance of the PMR practice in the context of agency performance goals</p> <p>Agency and external benefits and costs are quantified and analyzed on a life-cycle basis, and inputs, outputs, and outcomes are well defined</p> <p>An explicit, systematic, risk management framework is utilized to identify challenges and risks, and develop well-defined strategies for surmounting them</p>

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Part B, Table 19. PMR Practice CMF (continued).

Critical Success Factor	Component	Level 1	Level 2	Level 3
3. Emerging/ Innovative PMR Practice-Supportive Systems, Programs, and Budgets	Agency R&D	The agency does not engage in applied R&D of such practices	The agency occasionally undertakes applied R&D of such practices that may solve a problem of concern that others have not adequately addressed	The agency has an active in-house and/ or contract applied R&D program of practices focused on priority problems of concern that have not been adequately addressed
	Agency Pilot Testing	The agency rarely undertakes pilot testing of innovative practices	The agency occasionally undertakes pilot testing of practices that may solve a problem of concern that others have not adequately addressed	The agency regularly does pilot testing of practices focused on priority problems of concern that have not been adequately addressed
	Institutional Knowledge Management System	There is no formal system for sharing or compiling technical knowledge related to these practices, which resides among the experience of individuals	Key staff maintain their own individual systems for compiling, updating, and accessing information specific to these practices and share this technical knowledge informally or on an as-needed basis	An agency-wide knowledge management system is used to compile, update, and access specific information on these practices
	Access to Funding	Access to funding in support of such practices is ad hoc and ill-defined in the absence of any established budgetary process or program geared toward funding this type of innovation	Although there is no established budgetary process or program geared toward funding this type of practice, there are recognized opportunities to make the case as a "special project" outside of regular processes	The opportunity for making the case for such practices is through established budgetary and program processes that encourage innovation advocates to compete for funding
	Assistance from Support Functions: <i>Information technology, human resources, and procurement units and supporting systems</i>	Gaining assistance in the form of administrative and technical support, particularly for new initiatives, can be arduous to achieve	Gaining assistance in the form of administrative and technical support requires patience and persistence, particularly for new initiatives, but is typically achievable	Gaining assistance in the form of administrative and technical support is readily achievable, even for new initiatives
	Availability of Facilities, Equipment, and Test Sites	There is insufficient capacity in facilities, equipment, and test sites available within the agency or accessible through outsourcing to undertake such practices	The capacity in facilities, equipment, and test sites available within the agency or accessible through outsourcing to undertake such practice is barely sufficient, but can be expected to increase with the advancement of these practices	There is sufficient capacity in facilities, equipment, and test sites available within the agency or accessible through outsourcing to undertake such practice

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Part B, Table 19. PMR Practice CMF (continued).

Critical Success Factor	Component	Level 1	Level 2	Level 3
4. Friendly Culture and Organization Toward Emerging/ Innovative Practices	Leadership Support; Collaboration and Teamwork; Receptivity to New Ideas; Dedication to Continuous Improvement	Largely absent	Present in the organization units involved in this type of PMR practice	Pervasive throughout the agency
	Support from Internal Partners: As needed to advance such emerging PMR practice	There is little or no interest from sister units within the agency whose participation in advancing this practice is essential	There is some level of interest and ability to provide support in advancing this PMR practice from essential sister units, though not to the same degree as the lead unit	There is proactive, enthusiastic interest and support from sister units anxious to partner in advancing this PMR practice
	Organizational Barriers	There is one or more barrier within the organization to advancing this PMR practice, which is unlikely to be overcome	There is one or more barrier within this organization to advancing this PMR practice, which very likely can be overcome	There are no barriers within the organization to advancing this PMR practice
	Risk-Reward Response	Risk aversion with respect to this PMR practice and a general fear of failure will impede ability to advance it within the organization	There is a willingness to advance this PMR practice and accept the possibility of failure because of leadership support and accepted risk management strategies	The potential of failure is seen as a learning experience including by leadership and there is no hesitancy about advancing this PMR practice because risks and risk management are well understood
5. Staff Supportive of Emerging/ Innovative Practices	Innovation Champion(s): <i>Combination of technical expertise, passionate interest, and ability to lead</i>	There are staff members with some technical expertise and interest in participating or potentially leading this PMR practice, but no clear choice in terms of level of interest	There is at least one staff member whose technical expertise, level of interest, and leadership ability are sufficient to lead this PMR practice, but no backup if this person were to leave	There is a clear choice of who should lead this PMR practice on the basis of technical expertise, level of interest, and leadership skills, and one or more others who could step in if this person were to leave
	Staff Capacity	There is insufficient capacity in numbers of people and levels of expertise within the agency or accessible through outsourcing to undertake this PMR practice	The capacity in numbers of people and levels of expertise available within the agency or accessible through outsourcing to undertake this PMR practice is barely sufficient, but can be expected to increase with the advancement of the practice	There is sufficient capacity in numbers of people and levels of expertise available within the agency or accessible through outsourcing to undertake the PMR practice
	Knowledge Acquisition and Sustainability: <i>Learning practices; continuous education and training</i>	Acquisition of new knowledge is typically applied to modest, incremental improvement to existing practice, and support for continuous education and training is severely limited and unlikely to be available for this PMR practice	Key staff seek out opportunities to acquire and incorporate new knowledge or outside expertise that significantly improve existing practice, but limited resources are available for continuous education and training that could fill gaps in expertise for this PMR practice	The agency proactively provides opportunities for access to knowledge of leading edge practice; continuous education and training is a priority within the agency and will be available to support this PMR practice when needed

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Part B, Table 19. PMR Practice CMF (continued).

Critical Success Factor	Component	Level 1	Level 2	Level 3
6. Legal, Regulatory and Policy Issue Management	Liability Issues	Identified for this PMR practice but not adequately addressed	Identified for this PMR practice and addressed in a minimally acceptable manner	Formally addressed, included under risk assessment, and liability protection measures developed for this PMR practice
	Intellectual Property Issues	Identified for this PMR practice but not adequately addressed	Identified for this PMR practice and addressed in a minimally acceptable manner	Formally addressed, included under risk assessment, intellectual property partnerships available, and mechanisms in place to manage them for this PMR practice
	Legal and Regulatory Challenges	Identified for this PMR practice but not adequately addressed	Identified for this PMR practice in a minimally acceptable manner	Formally addressed and any issues related to this PMR practice have been resolved
	Policy Issues	There are potential policy-level conflicts related to this PMR practice that have been identified but not addressed	There are no known policy-level conflicts related to this PMR practice	There are policies in place which support advancing this PMR practice
7. External Collaboration	Interaction with Transportation Agency and Academic Peers	There is relatively little or no interaction with peers in relation to this PMR practice	There is active, well-organized, and regular interaction with peers in relation to this PMR practice	Interaction with peers in relation to this PMR practice has been extensive and has led to a collaborative, coordinated, and shared-risk approach
	Communication Beyond the Transportation Community	Little or no interactions beyond the transportation community in relation to this PMR practice	Ad hoc and limited interactions beyond the transportation community in relation to this PMR practice	Formal coordination mechanisms in-place tapping into expertise and experience beyond the transportation community in relation to this PMR practice
	Private-Sector Outsourcing and Partnering	No consideration given to outsourcing or sharing costs or managing risk for this PMR practice through partnering with the private sector	Private-sector outsourcing and partnering considered and utilized sparingly or not at all for this PMR practice due to procurement problems or conflicting goals	Private sector engaged in an optimum fashion for this PMR practice, through outsourcing activities performed more cost-effectively and through partnerships in which costs and risks are shared

Practice RAF

The Practice RAF lays out a high-level action plan for advancing the emerging and innovative practices. The term “advancing” (as opposed to “implementation”) is used since these practices may require testing and evaluation to confirm whether expectations support implementation. The RAF can be thought of as a proposal to provide the justification for moving forward with an agency commitment to the given practice. Use of the RAF (and the CMF) presumes that the potential value of the PMR practice to the agency is apparent to a certain degree although not completely understood. For this reason, the practice must be advanced through an iterative process that involves testing, evaluation, refinement and further testing, and evaluation.

Practice RAF Components

The Practice RAF contains four parts, A through D.

Part A—Addressing Practice CMF Gaps: This part involves actions to address key gaps identified from the CMF assessment. The specific actions should be formulated to progress the agency toward the targets established during the assessment. They should include the following:

- Designations of responsibilities for these actions.
- Other agency units or outside parties involved or affected and how effective collaboration will be established.
- Risks and potential barriers and how they might be addressed.
- A schedule for initiating and completing each action.
- Estimates of identifiable costs.

Part B—Agency-Specific Required Actions: This part describes other significant actions that will be required to formally incorporate the PMR practice into the agency, unit, or discipline’s work program and advance it through applied R&D, evaluation, testing, and demonstration phases (as applicable). These actions may not necessarily “fill gaps” but suggest essential steps of planning, coordination, and execution associated with agency work-program initiatives. These actions will be dictated by the agency’s processes and the practice being advanced.

For example, an agency may require that any new practice or initiative be vetted through a prescribed process of formulation and evaluation, done with sufficient consistency in format and in a timeframe to facilitate periodic decisions on competing proposals for inclusion in agency programs and budgets. An agency may require that any R&D activity related to the adoption of certain practices in PMR-related areas be subjected to a peer review that includes expertise from within and beyond the agency. The Practice RAF needs to include steps such as those indicated by these examples to indicate responsibilities, needed coordination and collaboration, and a schedule for initiating and completing each action.

Part C—Preliminary Long-Term Benefit–Cost Assessment: This part provides key information to make a go/no-go decision on whether to advance the practice by providing a preliminary, long-term benefit–cost assessment. This assessment is preliminary without having the benefit of a testing and evaluation stage that could help provide good estimates of costs and benefits. This benefit–cost assessment must draw upon the research and knowledge compiled on the PMR practice, including experience elsewhere, and the best and most objective estimates, even where good data are not available. As is likely in many cases, where these practices would supplant existing practices, it is important that the benefits and costs be incremental, in that they consider the change in costs and the change in benefits from existing practice. This stipulates a knowledge of

the costs and benefits attributable to existing practices to a level of accuracy comparable to the estimates for the emerging practice.

This preliminary benefit–cost assessment is part of the RAF, the purpose of which is to assist in determining whether to advance a given PMR practice to the testing and evaluation phase. A more precise benefit–cost assessment should be made following testing and evaluation of the proposed practice to assist in determining whether, when, where, and how to implement this practice.

Part D—Summary and Recommendation: This part summarizes the results of the Practice CMF and Parts A through C of the RAF, weighs the various options, and makes a recommendation on whether to advance the innovation to the testing and evaluation phase. Part B, Table 20 provides a template for completing the Practice RAF after the Practice CMF assessment.

Part B, Table 20. Practice RAF template.

Action	Responsibility (Person and Unit)	Supporting Units and Partners	Potential Barriers and Risks	Barrier and Risk Mitigation Strategy	Start and Completion Dates	Estimated Cost (Initial and Ongoing)
<p>Part A. Address Critical Success Factor Gaps from the CMF</p> <p>Part B. Identify Additional Key Action Items for the PMR Practice</p>						
<p>Part C. Perform Preliminary Agency- Wide, Long-Term Benefit-Cost Assessment for the Practice</p>						
<p>Part D. Summarize for Go/No-Go Decision</p>						

The Go/No-Go Decision

The Practice CMF assessment of capability, in combination with the Practice RAF action steps, should provide agency decision makers with the information they need to make a “go/no-go” decision on whether to advance the PMR practice to the testing and evaluation stage. It also provides an ability to move forward quickly as soon as a “go” decision is made.

The two-step process (assessing capability using the CMF) and determining required action steps using the Practice RAF will lead to one of four recommended paths that the agency might take to advance a specific practice:

1. “No-go”: Decide not to advance the PMR practice at this time because of:
 - a. Insufficient interest in the practice,
 - b. Insufficient capability,
 - c. Insufficient resources,
 - d. Inability to overcome barriers,
 - e. Inability to mitigate risks to an acceptable level, and
 - f. Some or all of the above.

Include a discussion of the consequences and ramifications of not advancing the practice.
2. “Not-now”: Continue to monitor progress with the PMR practice’s development and application elsewhere as well as all of the above factors that led to a “not-now” decision at this time, and revisit the decision when circumstances warrant. Include a discussion of the consequences and ramifications of not advancing the practice at this time and an indication of when revisiting would be prudent.
3. “Slow-go”: Decide to advance the practice but for some combination of reasons, do so at an “evolutionary” pace by naturally incorporating the practice into the agency’s routine as it becomes relatively mainstreamed. Include a discussion of the consequences and ramifications of a “slow-go” decision.
4. “Go-now”: Decide to expeditiously advance the practice into the agency’s mainstream PMR practices, including an expedited testing and evaluation phase, potentially in collaboration with others interested in advancing the practice within the transportation sector.

A final go/no-go decision may rest with agency senior management; therefore, the CMF and the Practice RAF should contain sufficient information to support such a recommendation and be packaged and summarized according to the preferences of those making the decision.

Since each Practice RAF is unique to the practice being considered and the agency’s individual context, an illustrative example, prepared assuming typical factors that may exist in an agency to illustrate CMF assessment outcomes, is provided in Part B, Appendix 4 (available as part of *NCHRP Web-Only Document 272*).

Suggested Practice RAF Actions

Part B, Table 21 provides a set of recommended, generalized actions to help the user identify and develop the actions necessary to populate a Practice RAF. These actions follow the organization of the CMF, with sets of several actions suggested for each CSF component.

- Actions marked with a check box denote those recommended for the practitioner to take.
- Actions marked with a bullet point require coordination with actions in the OIF or should be initiated at the leadership level because they pertain to organization-wide factors.

→ Clarifying notes are marked with an arrow.

Part B, Table 21. Practice RAF suggested actions.

Critical Success Factor	Component	Potential Target (Level 3)	Suggested Actions
<p>1. Awareness of Emerging PMR Practice</p>	<p>Context Awareness: <i>Leading edge practices; Status of R&D in progress; Problems being addressed; Alternative approaches being developed and tested</i></p> <p>Specific Awareness of the PMR Practice: <i>What it is; What it does; Where it should work well; Where it might not apply; Level of effort and resources required (staffing, expertise, facilities, equipment, time and budget)</i></p>	<p>High level of awareness and keen interest in closely following fundamental and applied R&D in this area</p> <p>Have been closely tracking the PMR practice and experiences in the testing and trials among early adopters</p>	<p>Develop, maintain and leverage awareness of the PMR practice's context</p> <ul style="list-style-type: none"> <input type="checkbox"/> Track state of practice via electronic and print media, conference attendance, committee participation, and peer dialogue <input type="checkbox"/> Develop and maintain an approach to assessing the applicability of the practice to existing PMR practices to which they might relate, their current performance and efficacy, and efforts to improve upon them <p>Develop and sustain a technical understanding of the importance of the PMR practice</p> <ul style="list-style-type: none"> <input type="checkbox"/> Stay abreast of the practice's application to other leading-edge practices relevant to the agency's context, including essential findings from fundamental and applied R&D, what problems are being addressed, and what alternative approaches are being contemplated and tested <input type="checkbox"/> Compile information on the application of the practice to highway PMR, as well as other agency services, activities, and practices, as deemed appropriate <input type="checkbox"/> Include considerations on where it should work well, where it might not apply, and the level of effort and resources required (staffing, expertise, facilities, equipment, time, and budget)

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Part B, Table 21. Practice RAF suggested actions (continued).

Critical Success Factor	Component	Potential Target (Level 3)	Suggested Actions
2. Performance Awareness and Application	Alignment with Agency Performance Goals	The PMR practice addresses a significant problem and an explicit performance goal of the agency	<p>Assess alignment of agency performance goals with candidate outcomes from applying the PMR practice</p> <ul style="list-style-type: none"> <input type="checkbox"/> Conduct a systematic review of discipline and agency goals with respect to state-of-the-practice performance and outcomes of the PMR practice <input type="checkbox"/> Articulate what problem is addressed by the practice and what explicit agency performance goal(s) can be supported <input type="checkbox"/> Develop an initial comparison of how the practice helps meet the performance goal to an extent that is superior to existing practice or that is otherwise unmet <p>Establish performance measures that indicate how the PMR practice would meet agency performance goals</p> <ul style="list-style-type: none"> <input type="checkbox"/> Identify appropriate metrics, data sources, analytics and approaches to capture the performance of the PMR practice with respect to a discipline, program, or activity goals—including both output and outcomes <input type="checkbox"/> Define and deploy practical performance measures that can be used to make decisions on the extent to which the practice is progressing in its application, to make comparisons with existing practice, and ultimately to address agency performance goals <input type="checkbox"/> Determine how performance-related input data will be captured and analyzed and how output data and outcomes will be acted upon and communicated, including roles and responsibilities
	Performance Measures	Full capacity to access historic performance data and applying measurement practices to define, apply, and communicate performance measures that characterize the performance of the PMR practice in the context of agency performance goals	
	Assessment of Anticipated Benefits and Costs	Agency and external benefits and costs are quantified and analyzed on a life-cycle basis, and inputs, outputs, and outcomes are well defined.	<p>Quantify the benefits and costs of the PMR practice</p> <ul style="list-style-type: none"> <input type="checkbox"/> Utilize performance data to quantify benefits and costs internal to the agency (e.g., improved asset performance or lower capital and life-cycle costs) <input type="checkbox"/> Quantify benefits and costs external to the agency to the extent feasible (e.g., improved customer satisfaction or improved resiliency) <input type="checkbox"/> Outline or estimate external benefits and costs where data or outcomes are insufficiently known <input type="checkbox"/> Incorporate benefit–cost results into a business case for the PMR practice, as necessary <p>→ Note: This action is also proposed as a separate step in the preparation of the complete Practice RAF to facilitate the go/no-go decision on advancing the practice; the completed Practice RAF forms the basis of a business case</p>

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Part B, Table 21. Practice RAF suggested actions (continued).

Critical Success Factor	Component	Potential Target (Level 3)	Suggested Actions
	Challenges and Risks	Challenges and risks have been thoroughly identified in an explicit, systematic, risk management framework that culminates in well-defined strategies for surmounting challenges and managing risks.	<p>Define and analyze challenges and risks associated with the PMR practice in a risk management framework</p> <ul style="list-style-type: none"> <input type="checkbox"/> Identify the scope and scale of the challenges and risks posed by a given PMR practice based on an internal review of peer/external entity experience relative to existing agency capabilities (business and technical processes, institutional context, and external collaboration) <input type="checkbox"/> Consider challenges and risks identified through the CMF assessment among all seven CSFs and the suggested actions throughout the Practice RAF to develop strategies to overcome the challenges and mitigate the risks <input type="checkbox"/> Articulate the findings in a formal risk management framework and utilize for initial assessment and ongoing evaluation and tracking <p>→ Note: This action is incorporated into the complete Practice RAF, which suggests identification of potential barriers and risks and mitigation strategies associated with each action taken to advance the select PMR practice</p>
3. Emerging and Innovative PMR Practice-Supportive Systems, Programs, and Budgets	Agency R&D	The agency has an active in-house and/or contract applied research and development program of innovations focused on priority problems of concern that have not been adequately addressed.	<p>Identify and implement the appropriate applied R&D approach to a given PMR practice</p> <ul style="list-style-type: none"> <input type="checkbox"/> Analyze the range of potential R&D approaches, including in-house, collaborative/pooled-fund, contracted, or “wait and see” regarding developments in other sectors <input type="checkbox"/> Consider agency capacity, costs, benefits, and risks to compare playing a leading role in applied R&D versus following and applying the results of peer agencies, the private sector (e.g., contractors, automotive manufacturers or suppliers, etc.), or leaders from other sectors (e.g., IT/telecom, technology, manufacturing, etc.) <input type="checkbox"/> Identify appropriate partners and their roles depending on the selected R&D approach—peer agencies/pooled fund program participants, consultants, universities, etc. <input type="checkbox"/> Develop the business case for pursuing applied R&D, if necessary <input type="checkbox"/> Develop a multiyear implementation plan (agenda, problems addressed, objectives, required resources, expected discipline interfaces and applications) for the given PMR practice’s applied R&D program

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Part B, Table 21. Practice RAF suggested actions (continued).

Critical Success Factor	Component	Potential Target (Level 3)	Suggested Actions
	Agency Pilot Testing	The agency regularly does pilot testing of practices focused on priority problems of concern that have not been adequately addressed.	<p>Determine the need for and scope of pilot testing associated with the PMR practice</p> <ul style="list-style-type: none"> <input type="checkbox"/> Consider whether the PMR practice is one for which the agency would (1) proactively lead pilot testing, (2) respond to outside entities' (such as contractors') proposals for development or piloting the emerging practice, or (3) accept the results of others' pilot tests as sufficient for the agency's purposes <input type="checkbox"/> If necessary, develop a staged plan for pilot testing of the PMR practice <input type="checkbox"/> Incorporate objectives, resources, locations, partners and roles, expected outcomes, and a formalized evaluation process of both success and explicit identification of failures, including consideration of whether additional testing is warranted or lessons can be applied <p>Assess the status of agency knowledge management system(s) with respect to the PMR practice and implement improvements</p> <ul style="list-style-type: none"> <input type="checkbox"/> Identify all existing sources of information within the agency and among relevant partners related to PMR practice identification, tracking, evaluation, and outcomes, whether it is an individual, unit, or external entity <input type="checkbox"/> Benchmark several mechanisms for sharing information related to existing practices within the agency • Evaluate potential, formal discipline-specific knowledge management systems appropriately scaled to the scope of the practice and sufficient to share and communicate information or if an agency-wide enhancement is necessary • Outline the essential parameters and protocols for the selected knowledge management system (data/information entry, organization, sharing, access, etc.) relevant to the PMR practice and consider developing a proposal to expand agency-wide as necessary <p>→ Note: Reference the OIF</p>
	Institutional Knowledge Management System	An agency-wide knowledge management system is used to compile, update, and access PMR practice-specific information	

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Part B, Table 21. Practice RAF suggested actions (continued).

Critical Success Factor	Component	Potential Target (Level 3)	Suggested Actions
	Access to Funding	The opportunity for making the case for this PMR practice through established budgetary and program processes that encourage advocates to compete for funding	<p>Rationalize the likelihood that adequate funding mechanisms can support investment in the PMR practice</p> <ul style="list-style-type: none"> <input type="checkbox"/> Estimate the required investments associated with the PMR practice in relation to planned actions in this Practice RAF (e.g., R&D, testing, demonstration, deployment, support functions, etc.) and their timeframes for execution <input type="checkbox"/> Consider PMR practice-specific versus general applications <input type="checkbox"/> Identify the scale of the investment and the extent to which these investments require substantial or dedicated funding <input type="checkbox"/> Determine whether funding can adequately derive from “special project” allocations or “one-off” opportunities, or whether formal, sustainable budget and program processes are needed to accommodate this PMR practice, either in the near term or long term
	Assistance from Support Functions: <i>Information Technology, human resources, procurement units, and supporting systems</i>	Gaining assistance in the form of administrative and technical support is readily achievable, even for new initiatives	<p>Ensure cooperation from support functions required to advance the PMR practice</p> <ul style="list-style-type: none"> <input type="checkbox"/> Identify interfaces with support functional units and appropriate systems related to advancing the PMR practice <input type="checkbox"/> Identify organizational barriers related to cooperation from these support functions and systems, considering practitioner staff engagement, and solicit ideas for improvement <input type="checkbox"/> Create an action plan for addressing identified barriers, recognizing that some barriers may be a product of longstanding institutional issues that require significant leadership investment to resolve (see: Organizational Barriers below) <input type="checkbox"/> Communicate the plan's intent with appropriate support function managers and obtain their buy-in <input type="checkbox"/> Pay particular attention to where top management needs to lead the way in initiating, communicating the need for, and authorizing any changes <p>→ Note: Reference the OIF</p>
	Availability of Facilities, Equipment and Test Sites	There is sufficient capacity in facilities, equipment, and test sites available within the agency or accessible through outsourcing to undertake the PMR practice.	<p>Confirm the need for and availability of facilities, equipment and test sites</p> <ul style="list-style-type: none"> <input type="checkbox"/> Determine the need for facilities, equipment, and test sites to examine the applications and outcomes of the PMR practice and identify options for providing such, in-house or outsourced

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Part B, Table 21. Practice RAF suggested actions (continued).

Critical Success Factor	Component	Potential Target (Level 3)	Suggested Actions
4. Innovation-Friendly Culture and Organization	<p>Leadership Support; Collaboration and Teamwork; Receptivity to New Ideas; Dedication to Continuous Improvement</p> <p>Support from Internal Partners:</p> <p><i>As needed to advance the PMR practice</i></p>	<p>Pervasive throughout the agency</p> <p>There is proactive, enthusiastic interest and support from sister units anxious to partner in advancing this PMR practice</p>	<p>No recommended action. This CSF component should be addressed within the OIF</p> <p>→ Note: Reference the OIF</p> <p>Collaborate with internal partners in other units to mutually benefit from the PMR practice</p> <ul style="list-style-type: none"> <input type="checkbox"/> Conduct education/outreach exercises (e.g., presentation at regular meeting, invitation to relevant external webinar, specific meeting around the PMR practice's application to an existing collaborative project, activity, or agency/unit objective) to bring together and inform internal partners of its significance <input type="checkbox"/> Ensure that the exercise aligns with internal partners' own goals and responsibilities <input type="checkbox"/> Continue to build on the collaboration begun with this approach and/or build on existing partner interest by obtaining participation from other units in the testing and deployment of the PMR practice at the appropriate juncture, and ideally when other units would see net benefits from its application to their own goals and responsibilities <p>Identify and eliminate organizational barriers that hinder or prevent advancing the PMR practice</p> <ul style="list-style-type: none"> <input type="checkbox"/> Identify organizational barriers to advancing the PMR practice that are not otherwise noted under Support from Internal Partners and Assistance from Support Functions above, considering practitioner staff engagement, and solicit ideas for improvement • Compile and communicate upward the practices and benefits evidenced by peer agencies (transportation or others) that are better organized for leading, facilitating, encouraging, or applying innovation • Create an action plan for addressing identified barriers, recognizing that some barriers may be a product of longstanding institutional issues that require significant leadership investment to resolve • Communicate the plan's intent with unit managers and obtain their buy-in and support for advocating changes • Pay particular attention to identifying the top management role in leading the way in initiating, authorizing, and communicating the rationale for needed changes <p>→ Note: Reference the OIF</p>

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Part B, Table 21. Practice RAF suggested actions (continued).

Critical Success Factor	Component	Potential Target (Level 3)	Suggested Actions
	Risk–Reward Response	The potential of failure is seen as a learning experience including by leadership, and there is no hesitancy about advancing the PMR practice because risks and risk management are well understood	<p>Leverage agency risk management processes to ensure identification of the potential for failure and how to learn from this experience</p> <ul style="list-style-type: none"> <input type="checkbox"/> Build into other actions related to innovation R&D, testing, demonstration, deployment, and support from other functions a plan to anticipate potential avenues of failure, mitigation if possible, and a methodology to capture lessons learned and extract positive outcomes from failure if occurs <input type="checkbox"/> Include a recovery approach and anticipatory options to continue innovation exploration in lieu of complete abandonment <input type="checkbox"/> Document these considerations in a “failure response strategy” <p>→ Note: Coordinate with other risk management planning, including as a part of the complete practice RAF the identification of potential barriers and risks and mitigation strategies associated with each action taken to advance the PMR practice</p>
5. Innovation-Supportive Staff	Innovation Champion(s): <i>Combination of technical expertise, passionate interest, and ability to lead this innovation</i>	There is a clear choice of who should lead this PMR practice on the basis of technical expertise, level of interest and leadership skills, and one or more others who could step in if this person were to leave	<p>Secure and empower a champion for the PMR practice innovation and immediate team</p> <ul style="list-style-type: none"> <input type="checkbox"/> Identify an existing staff individual as champion to lead the practice and provide that person with the capacity and resources (e.g., opportunities to engage in and learn from national state-of-the-practice activities) <input type="checkbox"/> If efficient or necessary, develop a recruitment approach to hire such a person with appropriate knowledge, skills, and abilities <input type="checkbox"/> Identify other key individuals to provide immediate support and position for succession <p>→ Note: Reference the OIF and coordinate with any actions taken related to an “innovation officer”</p> <p>Maintain appropriate staff capacity to advance the PMR practice</p> <ul style="list-style-type: none"> <input type="checkbox"/> In combination with the above action for Innovation Champion(s), identify key staff roles and capabilities necessary for exploration, development, and testing of the PMR practice <input type="checkbox"/> Develop appropriate knowledge/skills/abilities and position descriptions for these individuals <input type="checkbox"/> Identify and participate in industry professional capacity building activities germane to the PMR practice (e.g., webinars, workshops, peer exchanges) <p>→ Note: Reference the OIF</p>
	Staff Capacity	There is sufficient capacity in numbers of people and levels of expertise available within the agency or accessible through outsourcing to undertake the activities related to the PMR practice	

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Part B, Table 21. Practice RAF suggested actions (continued).

Critical Success Factor	Component	Potential Target (Level 3)	Suggested Actions
	<p>Knowledge Acquisition and Sustainability: <i>Learning practices; Continuous education and training</i></p>	<p>The agency proactively provides opportunities for access to knowledge of leading edge practice; continuous education and training is a priority within the agency and will be available to support this PMR practice when needed</p>	<p>Identify and ensure access to the necessary education and training to advance the PMR practice</p> <ul style="list-style-type: none"> <input type="checkbox"/> Identify sources of practice-relevant professional capacity building activities (training)—as above under Staff Capacity—including peer exchanges and dissemination of nationally-led pilots related to this practice <input type="checkbox"/> Where formal training is not available, identify where third-party assistance may be able to provide training (e.g., FHWA, associations, and universities) <input type="checkbox"/> Communicate upward the need and priority of the identified training needs <p>→ Note: Reference the OIF</p>
<p>6. Legal, Regulatory and Policy Issue Management</p>	<p>Liability Issues</p>	<p>Formally addressed, included under risk assessment, and liability protection measures developed for this PMR practice</p>	<p>Identify potential sources of liability related to the PMR practice and address as appropriate</p> <ul style="list-style-type: none"> <input type="checkbox"/> Systematically review practice for potential sources of liability to the agency, starting from known issues among peers and in consultation with appropriate legal advisors <input type="checkbox"/> Acquire appropriate legal protection measures <input type="checkbox"/> Where necessary, develop practice-specific liability protection instrument <input type="checkbox"/> Incorporate outcomes into the practice's risk management framework
	<p>Intellectual Property Issues</p>	<p>Formally addressed, included under risk assessment, intellectual property partnerships available, and mechanisms in place to manage them for this PMR practice</p>	<p>Identify intellectual property issues related to the PMR practice and address as appropriate</p> <ul style="list-style-type: none"> <input type="checkbox"/> Identify intellectual property issues associated with the practice, particularly during the R&D phase and when seeking partnership with external entities <input type="checkbox"/> Explore potential arrangements with intellectual property owners <input type="checkbox"/> Consult with appropriate legal advisors <input type="checkbox"/> Identify/execute appropriate agreements (nondisclosure agreements, use fees) to protect respective parties <input type="checkbox"/> Identify needed legal instruments <input type="checkbox"/> Incorporate outcomes into practice's risk management framework

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Part B, Table 21. Practice RAF suggested actions (continued).

Critical Success Factor	Component	Potential Target (Level 3)	Suggested Actions
	Legal and Regulatory Challenges	Formally addressed and any issues related to this PMR practice have been resolved	<p>Identify other legal and regulatory issues related to the PMR practice and address as appropriate</p> <ul style="list-style-type: none"> <input type="checkbox"/> Identify other legal and regulatory challenges (other than liability and intellectual property) related to the practice, including waste, fraud, abuse, competitive procurement violations, pricing, Occupational Safety and Health Administration requirements, state labor and union restrictions, and confidentiality <input type="checkbox"/> Review peer experience with these challenges relative to the PMR practice's context <input type="checkbox"/> Identify areas where compliance is an issue (barrier to) the PMR practice <input type="checkbox"/> Where necessary, access appropriate internal and external legal expertise to review issues and identify resolution <input type="checkbox"/> Develop standard operating procedures on an issue-by-issue basis <input type="checkbox"/> Incorporate outcomes into practice's risk management framework
	Policy Issues	There are policies in place which support advancing this PMR practice	<p>Identify agency policy issues related to the PMR practice and address as appropriate</p> <ul style="list-style-type: none"> <input type="checkbox"/> Identify agency policies that hinder or conflict with advancing the PMR practice, document options to overcome them, and communicate upward to senior management <input type="checkbox"/> Identify potential agency policies that would support the PMR practice, making connections to service and agency effectiveness and efficiency, and communicate upward to senior management <input type="checkbox"/> Incorporate outcomes into practice's risk management framework

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Part B, Table 21. Practice RAF suggested actions (continued).

Critical Success Factor	Component	Potential Target (Level 3)	Suggested Actions
7. External Collaboration	Interaction with Transportation Agency and Academic Peers	Interaction with peers in relation to this PMR practice has been extensive and has led to a collaborative, coordinated, and shared risk approach	<p>Collaborate and share knowledge with peers, and identify opportunities to share risks associated with advancing the PMR practice</p> <ul style="list-style-type: none"> <input type="checkbox"/> Identify logical and efficient areas for collaboration <input type="checkbox"/> Identify appropriate peers and forums through which transportation agency and academic peers interact and share knowledge <input type="checkbox"/> Consider the relevant roles and activities of other organizations (e.g., U.S. DOT/FHWA, AASHTO, TRB, academic institutions, regional and local government organizations or associations, and industry associations) <input type="checkbox"/> Participate in exchanges and opportunities to capture and share progress with leading edge research and development, lessons learned, and pilot test results <input type="checkbox"/> Focus particularly on opportunities to develop and participate in lead-agency risk-sharing mechanisms <input type="checkbox"/> Identify appropriate (legal) mechanisms to improve PMR practice-related dialogue with private sector entities
Communication Beyond the Transportation Community	Communication Beyond the Transportation Community	Formal coordination mechanisms in-place tapping into expertise and experience beyond the transportation community in relation to this PMR practice	<p>Establish exchanges beyond the transportation community to capitalize on outside expertise and mutually benefit from advancement of this PMR practice</p> <ul style="list-style-type: none"> <input type="checkbox"/> Using awareness and knowledge management tools (as developed under other CSFs), identify the key non-transportation sectors that are involved with this practice (R&D, evaluation, application, marketing) <input type="checkbox"/> Characterize their roles and potential relationships with or influence on the agency (e.g., lead developer/user, manufacturer/provider) or the transportation sector/highway PMR field more generally and appropriate mechanisms for building relationships <input type="checkbox"/> Identify specific collaborative and knowledge-exchange opportunities/venues with key players in other sectors in which goals in applying the PMR practice may overlap, and avenues through which coordination could overcome barriers to implementation

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Part B, Table 21. Practice RAF suggested actions (continued).

Critical Success Factor	Component	Potential Target (Level 3)	Suggested Actions
	Private Sector Outsourcing and Partnering	Private sector is engaged in an optimum fashion for this PMR practice, through outsourcing activities performed more cost-effectively and through partnerships in which costs and risks are shared.	<p>Engage the private sector through outsourcing or partnering in a manner that reduces costs and/or shares risk associated with the PMR practice</p> <ul style="list-style-type: none"> <input type="checkbox"/> Review existing agency policies, legal constraints, and contractual mechanisms for private-sector outsourcing and partnering with respect to the PMR practice <input type="checkbox"/> Identify the barriers to effective partnerships (e.g., legal, financial, contractual, competitive), where and how they have been overcome by peers, and appropriate mechanism for the specific PMR practice <input type="checkbox"/> Incorporate analysis into the business case developed as a part of the PMR practice benefit-cost assessment (see Performance Awareness and Application)

Fostering Emerging/Innovative Practices Within the Organization

The previous section focused on the assessment of the capabilities and actions required to decide on whether and how to advance a particular emerging/innovative practice using the PMR Practice CMF and the Practice RAF. Another, somewhat less specific but no less significant capability assessment can be done at either the agency-wide level or by a single organizational unit that assesses the capability to foster such practices. At the enterprise level, this may be a first order of business before delving into a specific practice to gauge how well the organization does in fostering continuous improvement, a learning environment, openness to new ways of doing business, a desire to move toward the leading edge, and an interest in advancing such PMR practices. At the practitioner level, working within an individual organizational unit, this may also be a first order of business for similar reasons or it may arise in response to a disappointing Practice CMF assessment.

This broader-based capability assessment can be done with a second type of CMF tool called the Organization CMF. This tool is applicable to individual units where discipline management and technical expertise reside (even without a specific emerging/innovative PMR practice in mind). It can also be used for the entire enterprise or specific parts of the organization where the CEO and senior managers may be interested in knowing how well they are cultivating and encouraging innovative practices across the entire agency.

Organization CMF

The Organization CMF can assist the practitioner in identifying capabilities of parts of the agency with which they are most familiar and that are critical to fostering innovative practices within the practitioner's areas of expertise and interest.

The Organization CMF encourages a top-level, self-assessment of the degree to which innovative practices are fostered throughout the enterprise. Leaders may or may not decide to address gaps as a matter of priority. However, 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 innovative practices are 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 innovative thinking within their technical domains. 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.

The same basic principles to conducting an assessment and interpreting its outcome described for the Practice CMF apply to the Organization CMF.

Who Leads the Assessment?

The assessment is led by discipline managers or technical practitioners interested in determining the capability of one or more specific units or disciplines to foster innovative practices. If performed collaboratively, participation from support functions such as human resources, legal and IT can be considered. Alternatively, agency senior management may initiate the assessment.

How Is the Assessment Conducted?

The assessment process is the same as for the Practice CMF, except that the evaluation is conducted by assessing capability in terms of the seven CSFs at high levels rather than examining their respective components. The criteria for each level within these factors pertain to fostering continuous improvement in general without a focus on any one practice in particular as is the case with the Practice CMF. The three levels of capability reflect the following characterizations:

- Level 1: The agency, unit, or discipline generally has not considered the CSF with respect to fostering innovative practices.
- Level 2: The agency, unit, or discipline 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, unit, or discipline has developed an approach to provide the CSF capability and it has been largely implemented.

What Is the Assessment Outcome?

As with the Practice CMF assessment, the outcome represents gaps in capability between current agency (or unit) practice and a threshold target level. Suggested actions to address those gaps are made in the OIF.

The Organization CMF

Part B, Table 22 presents the Organization CMF.

Part B, Table 22. The Organization CMF.

Critical Success Factor	Level 1	Level 2	Level 3
<p>1. Awareness with Innovative Practices</p>	<ul style="list-style-type: none"> • Little or no effort at an organizational level to foster interest and awareness in such practices • To the extent that interest and awareness in leading edge/innovative practices exist, both are highly dependent on individual initiative among motivated staff 	<ul style="list-style-type: none"> • 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 	<ul style="list-style-type: none"> • 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
<p>2. Performance Awareness and Application</p>	<ul style="list-style-type: none"> • 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 such practices • 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 	<ul style="list-style-type: none"> • 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 	<ul style="list-style-type: none"> • 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 • 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

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Part B, Table 22. The Organization CMF (continued).

Critical Success Factor	Level 1	Level 2	Level 3
<p>3. Emerging / Innovative Practice-Supportive Systems, Programs, and Budgets</p>	<ul style="list-style-type: none"> 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 	<ul style="list-style-type: none"> 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 	<ul style="list-style-type: none"> 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 to encourage advocates of innovative practices to compete for funding Administrative and technical support for new initiatives is readily available and provided proactively
<p>4. Innovation-Friendly Culture and Organization</p>	<ul style="list-style-type: none"> 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 legacy approaches, systems, criteria, and relationships among units 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 innovation Senior management projects a risk-averse posture toward innovation with the generally accepted notion that failure is not tolerated 	<ul style="list-style-type: none"> 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 	<ul style="list-style-type: none"> 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 and readily accepts it as a learning experience; innovators visibly recognized and rewarded

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Part B, Table 22. The Organization CMF (continued).

Critical Success Factor	Level 1	Level 2	Level 3
<p>5. Innovation-Supportive Staff</p>	<ul style="list-style-type: none"> Acquisition of new knowledge is typically the result of modest, incremental improvement to existing practice Support for continuous education and training that might stimulate interest in innovative practices is severely limited or unavailable 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 Recruitment and retention decisions are based on candidates' professional knowledge related to existing practices rather than areas that may support innovative practices 	<ul style="list-style-type: none"> Some, but not all key staff, proactively seek opportunities to acquire and incorporate new knowledge that can significantly improve existing practice Continuous education and training opportunities to foster innovative practices have been identified, but limited resources can make it difficult to access them 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 New hires possessing skills and interest in leading edge practices and applying innovation are often prioritized but may be difficult to recruit 	<ul style="list-style-type: none"> 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 innovation 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/innovative practices to their roles and responsibilities; agency's reputation as an innovative institution helps to attract these individuals
<p>6. Legal, Regulatory and Policy Issue Management</p>	<ul style="list-style-type: none"> 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 innovation 	<ul style="list-style-type: none"> 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 	<ul style="list-style-type: none"> 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

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Part B, Table 22. The Organization CMF (continued).

Critical Success Factor	Level 1	Level 2	Level 3
<p>7. External Collaboration</p>	<ul style="list-style-type: none"> 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 	<ul style="list-style-type: none"> 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 	<ul style="list-style-type: none"> 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

The OIF should contain at a minimum a description of the agency's (or unit's) existing practices and capabilities with respect to the CSFs, 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 targets. Part B, Table 23 provides suggested actions by CSF as the key component of the OIF; details for implementing these actions are left to the agency or user's discretion.

Part B, Table 23. OIF suggested actions.

Critical Success Factor	Components	Potential Target (Level 3)	Suggested Actions
1. Awareness	<p>➤ Context Awareness:</p> <p><i>Leading edge practices</i></p> <p><i>Status of R&D in progress</i></p> <p><i>Problems being addressed</i></p> <p><i>Alternative approaches being developed and tested</i></p>	<ul style="list-style-type: none"> • 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 	<ul style="list-style-type: none"> <input type="checkbox"/> 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: <ul style="list-style-type: none"> o Tracking and gauging the effects or influences of long-term drivers of change and resulting future scenarios, such as those identified in this guide o Understanding the PMR implications of the drivers and potential future scenarios o 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 o 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 o Participating in peer groups and regional and national forums related to innovative practices of greatest interest <input type="checkbox"/> Initiate an internal “awareness vehicle” (e.g., website, newsletter) <input type="checkbox"/> 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 <p>→ Note: The individual in this position is recommended to lead or facilitate a number of the actions suggested in the other CSFs</p>

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Part B, Table 23. OIF suggested actions (continued).

Critical Success Factor	Components	Potential Target (Level 3)	Suggested Actions
2. Performance Awareness and Application	<ul style="list-style-type: none"> ➤ Alignment with Agency Performance Goals ➤ Performance Measures ➤ Assessment of Anticipated Benefits and Costs ➤ Challenges and Risks 	<ul style="list-style-type: none"> • 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 	<ul style="list-style-type: none"> <input type="checkbox"/> Initiate a systematic benchmarking exercise of agency PMR activities compared to the state-of-the-practice and articulate a performance-based vision for improvement <input type="checkbox"/> 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 <input type="checkbox"/> Intensify and deepen overall agency commitment to the use of performance measures and benefit-cost analysis in both program design and operations <input type="checkbox"/> Familiarize staff with case studies that demonstrate the positive impact of innovation on PMR and agency performance <input type="checkbox"/> Establish a process where units' and individuals' recognition or rewards are related to utilization of performance measures (not necessarily the performance changes themselves) <input type="checkbox"/> Establish a formal innovation-related risk assessment process as appropriate to PMR activities
3. Emerging/ Innovative PMR Practice Supportive Systems, Programs, and Budgets	<ul style="list-style-type: none"> ➤ 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 	<ul style="list-style-type: none"> • 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 	<ul style="list-style-type: none"> <input type="checkbox"/> 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 <input type="checkbox"/> Develop and institute a formal process/program to initiate and support application of innovative practices, building on the program established under Awareness <input type="checkbox"/> 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 <input type="checkbox"/> 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

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Part B, Table 23. OIF suggested actions (continued).

Critical Success Factor	Components	Potential Target (Level 3)	Suggested Actions
<p>4. Improvement/Change-Friendly Culture and Organization</p>	<ul style="list-style-type: none"> ➤ Leadership Support ➤ Collaboration and Teamwork ➤ Receptivity to New Ideas ➤ Dedication to Continuous Improvement ➤ Organizational Barriers ➤ Risk-Reward Response 	<ul style="list-style-type: none"> • 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 	<ul style="list-style-type: none"> <input type="checkbox"/> Use the leadership "pulpit" to talk about, celebrate, and reward interest in and actions taken toward improvement <input type="checkbox"/> Encourage and support education/outreach exercises among staff that share experience with innovative practices (e.g., discipline or PMR practice-focused meetings, webinars, etc.) <input type="checkbox"/> Conduct peer-to-peer workshops with top and middle management focused on improvement successes <input type="checkbox"/> 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 <input type="checkbox"/> 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 <input type="checkbox"/> 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 <p>→ Note: The innovation officer can lead or facilitate the activities suggested by these actions</p>

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Part B, Table 23. OIF suggested actions (continued).

Critical Success Factor	Components	Potential Target (Level 3)	Suggested Actions
5. Improvement/Change-Supportive Staff	<ul style="list-style-type: none"> ➤ Knowledge Acquisition and Sustainability: <i>Learning practices</i> <i>Continuous education and training</i> ➤ Staff Capacity ➤ Recruitment and Retention 	<ul style="list-style-type: none"> • 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 	<ul style="list-style-type: none"> <input type="checkbox"/> 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 <input type="checkbox"/> Identify key roles necessary to support other actions taken within the OIF and develop position descriptions and target knowledge, skills and abilities <input type="checkbox"/> Review recruitment practices, job descriptions, promotion and other career development factors for opportunities to incentivize improvement <input type="checkbox"/> Provide support, both funding and a permitted allocation of staff time, to participate in professional capacity building activities that advance innovation knowledge <input type="checkbox"/> 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	<ul style="list-style-type: none"> ➤ Liability Issues ➤ Intellectual Property Issues ➤ Legal and Regulatory Challenges ➤ Policy Issues 	<ul style="list-style-type: none"> • 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 	<ul style="list-style-type: none"> <input type="checkbox"/> Seek support from attorneys who focus as much on "can-do" solutions as on "can't do" barriers <input type="checkbox"/> Look at how peers have tackled similar issues <input type="checkbox"/> Seek authority to perform trial or pilot actions that test whether and how legal, regulatory, or policy constraints can be addressed <input type="checkbox"/> Initiate processes to modify policies, regulations, and/or statutes that unreasonably discourage or constrain opportunities for innovative practices

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Part B, Table 23. OIF suggested actions (continued).

Critical Success Factor	Components	Potential Target (Level 3)	Suggested Actions
7. External Collaboration	<ul style="list-style-type: none"> ➤ Interaction with Transportation Agency and Academic Peers ➤ Communication Beyond the Transportation Community ➤ Private-Sector Outsourcing and Partnering 	<ul style="list-style-type: none"> • 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 	<ul style="list-style-type: none"> <input type="checkbox"/> 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) <input type="checkbox"/> Identify and support mechanisms for key professional staff involvement in external networks involved in innovative practices <input type="checkbox"/> Establish a budget to support technical activities relevant to innovative practices, including travel and training <input type="checkbox"/> Establish a forum on innovative practices with outside technical experts on a continuing basis <input type="checkbox"/> Utilize the request for information (RFI) process to identify external innovative concepts <input type="checkbox"/> Investigate methods of establishing increased interaction with private industry, while recognizing legal and regulatory constraints, and capitalize on available opportunities (conferences, workshops, etc.) <input type="checkbox"/> Investigate options for public-private partnerships, including special public-private entities to manage innovative-intensive programs or projects <input type="checkbox"/> 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



APPENDICES 1 THROUGH 5

Part B, Appendices 1 through 5 are part of *NCHRP Web-Only Document 272* and can be downloaded from trb.org by searching for “NCHRP Report 750, Volume 7.”

These appendices are as follows:

Part B, Appendix 1 Long List of Emerging Highway PMR Practices

Part B, Appendix 2 Emerging and Innovative PMR Practice Database

Part B, Appendix 3 The Capability Maturity Model

Part B, Appendix 4 Emerging PMR Practice and Innovation Capability Maturity Framework Assessment Illustrative Example

Part B, Appendix 5 Innovation Required Actions Framework (IRAF) Illustrative Example