Workforce Development Needs of Transportation Sector Climate Adaptation Professionals

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A White Paper from the National Center for Sustainable Transportation

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National Center for Sustainable Transportation

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16. Abstract
Climate adaptation is now a well-documented need in the transportation sector, and there are strong conceptual frameworks for the adaptation process. Since climate adaptation is an emerging field, the pathways for developing the skills and competencies for adaptation careers are not well established. This white paper assesses the workforce development needs and current training opportunities related to transportation-sector climate adaptation. To do so, training needs were examined and opportunities identified by state and regional transportation agencies; training needs of aspiring and early-career climate adaptation professionals were cataloged; and a scan was completed of the educational opportunities in climate adaptation currently offered by universities in the United States. There is evidence of convergence on the areas of content knowledge, technical expertise, and soft skills that form the core competencies necessary to support climate adaptation within the transportation sector. These core competencies are in climate science, adaptation strategies, communication, and selection of adaptation measures/decision making under uncertainty. While these competencies need to be broadly distributed throughout transportation agencies, the relative emphasis placed on each competency will vary across agency functions and job responsibilities. The increased value placed on adaptation-related expertise by state departments of transportation and regional transportation agencies, as well as the emergence of new educational and training opportunities in climate adaptation available in higher education and professional organizations, is indicative of the potential for rapid growth in this area.

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EXECUTIVE SUMMARY

Early investments in climate change research, policy, and planning focused heavily on climate mitigation—efforts to reduce greenhouse gas emissions. As climate change impacts have increased in severity, this focus has broadened to include a greater emphasis on climate change adaptation—efforts to minimize the adverse impacts of climate change through hardening or relocating infrastructure, changing design standards, improving redundancy, and other measures. Building climate adaptation capacity within transportation agencies is not straightforward, however, because the knowledge base for climate adaptation is changing rapidly and because the process itself is inherently complex. Moreover, climate change impacts and, therefore, adaptation strategies vary regionally as agencies must manage stressors as varied as sea level rise, increased precipitation, extreme temperatures, reduced slope stability, and thawing permafrost. The growing emphasis on climate adaptation has created a demand for professionals with a new, interdisciplinary skillset. Since climate adaptation is an emerging field, the pathways for developing the skills and competencies for adaptation careers and their broad integration into transportation agencies are not well established.

This white paper assesses the workforce development needs and current training opportunities related to transportation-sector climate adaptation. To understand the climate adaptation workforce development environment, we examine training needs and opportunities identified by state and regional transportation agencies; catalog the training needs of aspiring and early-career climate adaptation professionals; and scan the educational opportunities in climate adaptation currently offered by U.S. universities. Training needs and opportunities identified by transportation agencies were collected through an online survey developed by the authors. The experience of aspiring adaptation professionals was captured in a unique survey conducted by the American Society of Adaptation Professionals (ASAP) as part of their mentorship program. Current graduate educational programs related to climate adaptation were identified during this project through a web-search. These diverse datasets, combined with lessons learned from existing adaptation initiatives, provide unique insights into the competencies needed for climate adaptation as well as the current capacity for training adaptation professionals.

We conclude that climate adaptation is now a well-documented need in the transportation sector and there are strong conceptual frameworks for the adaptation process. Implementation of adaptation processes requires significant changes to traditional practices within transportation agencies. Adaptation places a greater imperative on collaboration across agencies and agency functions and will require professionals with a broader set of proficiencies than have been historically necessary. The development of the adaptation workforce is still in the early stages, but the increased value placed on adaptation expertise by Departments of Transportation (DOTs) and regional transportation agencies as well as the emergence of new

educational and training opportunities in climate adaptation available in higher education and professional organizations is indicative of the potential for rapid growth in this area.

There is evidence of convergence on the areas of content knowledge, technical expertise, and soft skills that form the core competencies necessary to support climate adaptation within the transportation sector. These core competencies are in:

- **Climate Science**: A basic understanding of climate change and local climate trends needs to be embedded throughout transportation agencies. At the most basic level, this helps staff understand the broad pattern of climate threats in their region that will inform almost all aspects of agency operations. A more advanced understanding of climate science and climate modeling facilitates the successful, in-depth collaboration with climate modelers that may be necessary to obtain and understand high-quality, localized, climate forecasts with actionable spatial resolution.
- **Adaptation Strategies**: A general understanding of the strategies that can be used to reduce climate risk also needs to be present throughout transportation agencies. As demonstrated in the Adaptation Training Needs and Opportunities survey and other work, most agency functions are or will be impacted by climate change. A broad understanding of how to respond to these impacts needs to be widely available, while a more detailed understanding of specific strategies, ranging from procedural changes in maintenance and options through long-term relocation of transportation assets and flexible design approaches, needs to be concentrated within different agency branches.
- **Communication**: Communication skills take on an outsized role in many components of the climate adaptation process. These skills are necessary for managing climate skepticism inside and outside of transportation agencies, making the case for adaptation funding, engaging stakeholders in scenario planning and complex conversations about risk, and promoting collaboration across traditionally siloed disciplines.
- **Selection and Prioritization of Adaptation Measures/Decision Making Under Uncertainty**: One of the greatest challenges in adapting to climate change is the considerable and inherent uncertainty in the magnitude of future climate change and climate change impacts. This uncertainty means planners and engineers must consider a range of possible extremes while designing the transportation system rather than designing for a known and relatively static set of weather conditions. This requires stress testing designs against a range of future extremes, looking for design options that maintain future flexibility, and engaging stakeholders to determine a societally acceptable balance of risk and cost. In this context, scenario planning, tools for understanding assets criticality in the context of complex network dynamics, economic analysis, and life-cycle assessment as well as innovative engineering practices are all needed to ensure that a full range of adaptation options are considered and that project selection and prioritization are equitable and effective.

While these competencies need to be broadly distributed throughout transportation agencies, the relative emphasis placed on each competency will vary across agency functions and job

responsibilities. Future research on climate adaptation workforce needs should work to delineate the degree of understanding and specific proficiencies required in each of these core areas for planners, engineers, asset managers, and operations and maintenance personnel.

Introduction

Alterations to historical climate and weather patterns resulting from anthropogenic climate change are associated with increased stressors on the transportation system. Moreover, climate change has been linked to an increase in extreme weather events that degrade transportation system infrastructure integrity, reliability, level of service, and user safety while also increasing the financial pressures on transportation agencies across the United States (*1*). The burden of preparing for and recovering from these events can tax the financial and human resources of transportation agencies at all levels. The indirect costs associated with longer travel times and reduced level of service impose wider societal costs. In response to these new and intensifying events and hazards, transportation agencies are placing increasing emphasis on developing and implementing adaptation strategies that reduce the transportation system's vulnerability to climate change.

Early investments in climate change research, policy, and planning focused heavily on climate mitigation—efforts to minimize the magnitude of climate change by reducing greenhouse gas emissions rates. In recent years, as current and near-term climate change impacts have increased in severity, this focus has broadened to include a greater emphasis on climate change adaptation—efforts to minimize the adverse impacts of climate change through hardening or relocation infrastructure, changing design standards, improving redundancy and other measures (*2–4*). The inclusion of adaptation as well as mitigation initiatives in the response to climate change represents a recognition of current and unavoidable future impacts of climate change. Adaptation initiatives are essential to the resilience of the transportation system in the face of increasingly severe climate threats, as the failure to adapt will result in repair and recovery efforts absorbing an ever increasing share of limited transportation resources.

Climate adaptation efforts have increasingly been incorporated into transportation and planning agencies at the federal (*5*), state (*6*), and local levels (*7*). The process of building climate adaptation capacity within these transportation agencies is not straightforward because the knowledge base for climate adaptation is rapidly changing and because the process itself is inherently complex and requires coordination across a range of agencies and agency functions. Moreover, climate change impacts and, therefore, adaptation strategies vary regionally, as agencies must manage stressors as varied as sea level rise, increased precipitation, extreme temperatures, reduced slope stability, and thawing permafrost. Climate adaptation involves allocating limited resources while balancing significant climatological uncertainties, differential infrastructure vulnerability, overall system-level criticality, and social equity. These efforts often require a major expansion of coordination with external partners. Strengthened interagency collaborations between transportation agencies, Departments of Natural Resources, State Climatologist and/or university partners are essential for ensuring that adaptation efforts incorporate the best available climate projections. Coordination among state, regional, and local transportation agencies is necessary to ensure that adaptation efforts are mutually supporting as the redundancy and resilience of the transportation network is dependent on interconnect road, pedestrian and transit systems, irrespective of the ownership and management of the infrastructure. Similarly, coordination between the transportation sector

and other infrastructure-intensive sectors such as the power and water resource sectors would enable mutually reinforcing adaptation measures. The growing emphasis on climate adaptation has created a demand for professionals with a new, interdisciplinary skillset. Currently, most of the professionals working in climate adaptation began their careers in other fields (*8*), and early research indicates that there is a widespread need for improved expertise in the area of climate adaptation (*9–13*). However, because climate adaptation is an emerging field, the pathways for developing the skills and competencies for adaptation careers in the transportation field are not well established.

This white paper assesses the workforce development needs and current training opportunities related to transportation-sector climate adaptation. It focuses on the work of state Departments of Transportation (DOTs) and Metropolitan Planning Organizations (MPOs) but includes lessons that have broad applicability to transportation actors in the for-profit and nonprofit sectors. To understand the climate adaptation workforce development environment, this paper examines training needs and opportunities identified by DOTs and MPOs; catalogs the training needs of aspiring and early-career climate adaptation professionals; and scans the educational opportunities in climate adaptation currently offered by universities in the United States. DOT- and MPO-identified training needs and opportunities were collected through an online survey, Climate Adaptation Training Needs and Opportunities, developed by the authors and distributed to DOTs and MPOs in late 2017 through early 2018. The experience of aspiring adaptation professionals was also captured in a unique survey conducted by the American Society of Adaptation Professionals (ASAP) in 2018 as part of their mentorship program. While the ASAP mentorship program is not specific only to mentees working or studying directly in the transportation sector, the inter-disciplinary and even multi-sectoral nature of climate adaptation makes the survey data broadly applicable to the transportation workforce. Analysis of this survey provides valuable insight into the professional development opportunities that will be required to develop a transportation workforce that is skilled in climate adaptation. Finally, current graduate educational programs related to climate adaptation were identified during this project and cataloged through a web-search. Particular emphasis was placed on documenting the fields/disciplines that are offering adaptation programs. Specific attention is also given to adaptation concentration and certificate programs since these are often complementary to traditional degree programs, and key adaptation principles will need to be embedded alongside other traditional disciplinary skills for the successful integration of adaptation principles within the transportation sector.

The diverse data sources used in this white paper demonstrate a clear need for climate adaptation training as well as a growing set of opportunities, within transportation agencies and in higher education, to obtain adaptation-related skills. While these training and educational opportunities are increasing, opportunities are currently relatively limited. Expanding these opportunities would benefit both the professionals looking to develop a career in climate adaptation and the transportation agencies that are looking to grow their capacity in this area. These data sources also make clear that there is not a singular adaptation specialization or career path. Rather, new competencies related to climate adaptation need to be distributed across many roles and fields in transportation agencies. This will endow agencies

with a more robust capacity to engage in climate adaptation. To move this process forward will require the retooling and incorporation of adaptation training standards in many traditional disciplines.

This paper is intended to provide an overview of the basic training needs of transportation staff for transportation agency leaders and policymakers, particularly those working in jurisdictions that that are not currently at the forefront of climate adaptation efforts. Moreover, it provides a road map for adaptation researchers and educators looking to develop curriculum to support adaptation-related training and certification.

The remainder of this paper is organized as follows. The Background section documents transportation sector climate adaptation efforts led by the Federal Highway Administration (FHWA) since 2010 as well as two multi-sector reviews of the state of climate adaptation in the United States conducted by the state of California and by the Kresge Foundation. This section provides an overview of the conceptual process of climate adaptation and highlights challenges and future workforce needs identified in recent adaptation initiatives. The subsequent two sections describe the execution and results of the Climate Adaptation Training Needs and Opportunities survey and data from the ASAP mentorship program. Thereafter, the Higher Education Climate Adaptation Programs section provides an overview of the current certificate and graduate degree programs. Finally, the Conclusions section synthesizes information from these diverse datasets, including the core competencies needed to support expanded climate adaptation efforts.

Background

The FHWA has been a major driver of climate adaptation efforts in the transportation sector. It has developed a variety of tools and guidance documents to support climate adaptation and has funded a growing number of adaptation pilot projects. Other infrastructure-heavy sectors such as the electric power and water resource sectors also have widespread and long-lasting hard infrastructure assets facing intensifying climate stressors and need expanded expertise in climate adaptation. Adaptation workforce needs from these and other sectors are likely to overlap with those in the transportation sector, since many of the components of climate adaptation (e.g., the assessment of climate data, infrastructure vulnerability, and risk) are common across sectors. Here, we summarize the FHWA's adaptation initiatives, prior work by the authors of this white paper on climate adaptation barriers and workforce needs, and work by the state of California and the Kresge Foundation that examines the state of climate adaptation across multiple sectors. We highlight a common set of barriers across these resources that are likely to inform the future of climate adaptation workforce development needs.

Beginning in 2010-2011, the FHWA worked with DOTs, MPOs, and other transportation organizations to pilot climate adaptation efforts, with 60 such projects completed or currently underway (*14*). The FHWA's Vulnerability Assessment and Adaptation Framework (hereafter "the Framework") is now in its third edition (*15*) and presents an iterative six-step process for climate adaptation consisting of the following actions:

1. Articulating objectives and defining study scope;
2. Obtaining asset data;
3. Obtaining climate data;
4. Assessing vulnerability;
5. Identifying, analyzing, and prioritizing adaptation options; and
6. Incorporating assessment results into decision-making.

Ongoing monitoring and evaluation of climate risks, asset conditions, and the effectiveness of adaptation efforts creates a foundation for reassessing vulnerabilities and iterating through the adaptation process. As documented in prior work by members of this white paper team, the FHWA Framework is broadly similar to other adaptation protocols, and the conceptual understanding of the steps involved in the process is relatively high, though significant practical and technical challenges must be overcome in order to successfully put adaptation protocols into practice (*13*).

In a prior NCST white paper, our research team categorized climate adaptation as either *process* adaptations or *infrastructure* adaptations (*12*). Process adaptations are changes to agency practices that can improve the response to severe events and support future infrastructure adaptations. Process adaptations include actions such as improving procedures for communication, data collection and infrastructure monitoring; changing maintenance schedules; and considering climate risk in the planning process. These adaptations tend to be

relatively low cost and implementable even with a high degree of uncertainty about the magnitude of climate change impacts in a region. Infrastructure adaptations aim to reduce the impact of extreme events. These adaptations tend to be more expensive and require more specific modeling or assumptions about future extreme events and include actions such as strengthening and protecting infrastructure, enhancing redundancy, and abandoning vulnerable infrastructure (*12*).

Throughout the FHWA Framework, there is an emphasis on stakeholder engagement, cross-cutting collaboration within transportation agencies, and significant interagency collaboration. The Framework envisions a role for agency personnel working in all phases of planning, building, and maintaining transportation infrastructure. The Arizona Department of Transportation's (ADOT) 2015 initiative, "Extreme Weather Vulnerability Assessment," is an excellent example of this kind of collaboration, with focus groups that included representatives from four different ADOT divisions and four different maintenance districts as well as three external Arizona State Departments, multiple nonprofit and educational entities, the FHWA, and the Bureau of Land Management (*16*). A collaborative, interagency approach to adaptation is also crucial because transportation networks and climate impacts do not align with jurisdictional boundaries. As discussed in Aultman-Hall and Dowds (*10*), several aspects of the adaptation process, including developing localized climate projections and assessing asset criticality, inherently cross jurisdictional boundaries. Replicating these efforts within each jurisdiction rather than working on them collaboratively leads to the duplication of effort and potentially sub-optimal adaptation actions (*10*).

The FHWA Framework notes several training needs and challenges facing agencies conducting vulnerability assessment and adaptation efforts. These include obtaining and utilizing projected climate data, incorporating risk assessment in agency processes, and determining how best to analyze and prioritize adaptation options. Shifting climate and weather patterns means that the practice of using long-established, historical weather data to inform infrastructure design is no longer appropriate or adequate. Consequently, agencies must use projected climate and weather data, which have significant uncertainty associated with them since there are a wide range of possible greenhouse gas emissions pathways over the next several decades. The Framework suggests using projections from a range of models and climate scenarios, especially for longer-term timeframes, in order to capture the full range of these uncertainties (*15*). Obtaining these data often requires collaboration with new partners, especially to get data from regional climate models that produce data at an appropriate geographic scale for vulnerability assessment and infrastructure design. Since design decisions have traditionally been made using static historical data, incorporating a range of potential future conditions into the planning and design processes creates new procedural challenges. Determining which emissions/climate scenarios should be used as the basis for design criteria should likely be part of a larger societal conversation, which has not been a historical part of the design process. The Framework report notes, for example, that the Port Authority of New York and New Jersey mandates that designers consider a mean annual temperature increase of 6°F and a mean annual precipitation increase of 10% by 2080. Training for risk-based planning, which considers both the probability and consequence of a particular climate impact, is another new process

recommendation for planning, design, construction, and maintenance staff (*15*). Analyzing and prioritizing adaptation options also require expanding agency expertise. The Framework report highlights a variety of economic analysis methods as well as multi-criteria analysis as potential analytical tools to support this process. Overall, the report highlights the need to integrate adaptation efforts throughout agency functions, placing new demands on collaboration, data collection, assessment, and agency outreach.

Key lessons from the first two rounds of the pilot program, which included 19 adaptation initiatives, are documented in FHWA's 2016 report: 2013-2015 Climate Resilience Pilot Program: Outcomes, Lessons Learned, and Recommendations (*17*). Similar to the Framework itself, this report is intended for an audience that includes planners, asset managers, and engineers, indicating the breadth of expertise that must be brought to bear in order to successfully engage in the climate adaptation process. While the report documented the conceptual strength of the adaptation framework and the success of the pilot projects in building staff capacity related to climate adaptation, it also outlined several challenges that inhibit comprehensive planning and implementation of adaptation measures. Notably, these challenges included the need for better guidance on how to use climate information, conduct benefit-cost assessments, and fully integrate vulnerability assessment into agency operation. Securing funding for the analysis of adaptation strategies was also highlighted as a frequent barrier to implementing adaptation strategies. In order to complete these pilot efforts, participating agencies frequently needed to limit the scope of their assessments (in terms of threats and infrastructure considered) due to the project timeline and shortcomings in climate and asset data quality and availability. In several cases, agencies also resorted to using historical weather and incident data as well as only qualitative methods for vulnerability and criticality assessment. While these decisions make sense in the context of the pilot program, and the projects generally produced actionable results, they nonetheless point to the challenges that remain for large-scale adaptation initiatives that examine a full range of climate hazards.

In addition to its Vulnerability and Adaptation Framework, the FHWA has produced resources geared specifically toward planning (*18*) and engineering (*19*) as well as maintenance and transportation systems management, and operations (TSMO) (*20*). Currently, the most active DOTs and MPOs are considering climate risk when defining goals and objectives for transportation planning and have begun to establish resilience performance metrics, but few are yet tracking these metrics in an on-going way (*18*). The TSMO Guide reported a set of knowledge and capacity gaps that currently inhibit transportation resiliency (*20*). These gaps included several issues related to organizational culture, external collaboration, and workforce capacity. Cultural and collaborative barriers include a lack of consensus about the importance of climate change, lack of awareness of climate change impacts, organizational risk aversion that inhibits the capacity to change historical practices, and lack of comfort and familiarity in collaborating with climate scientists in order to understand climate projections and uncertainties. Workforce issues include that overburdened staff have limited capacity and training to consider climate change risk or develop adaptation responses. The report suggested ensuring TSMO staff understand the impact of climate change on day-to-day operations and

potentially create hybrid job classifications that draw on expertise in engineering, environmental science, and emergency management.

Many of the training and data needs identified throughout the FHWA's adaptation initiatives are consistent with those identified in prior research involving this white paper team (*10*–*13*). Preliminary interviews with DOT and MPO personnel indicated that the adequacy of tools and data to implement each of the steps in the adaptation process was highly variable, with significant challenges related to assessing climate threats and prioritizing and executing adaptation options (*13*). A 2015 survey, the Climate Adaptation Planning (CAP) survey, of 154 individuals from 120 transportation agencies showed a relatively low confidence in the adequacy of staff knowledge related to climate adaptation (with an average rating of 5.1 on a 1–10 scale) as well as in the adequacy of the tools available to assess climate threats (4.7), evaluate infrastructure vulnerabilities (5.0), rate asset importance (5.2), and identify and execute adaptation options (4.1) (*10*). A total of 90 of the survey participants (58%) responded to an open-ended question on professional development needs related to climate adaptation, 80% of whom indicated current professional development gaps. The most common need identified by these respondents was the need for basic seminars on climate change and climate adaptation. Other needs included training on cost-benefit analysis, risk assessment, and guidance on how to obtain and use local climate data (*11*).

In 2018, the Climate-Safe Infrastructure Working Group (CSIWG), created in response to California's Climate-Safe Infrastructure Bill (AB 2800), released a report on responding to climate change throughout the infrastructure design, planning, and implementation processes (*21*). The report considered infrastructure across a range of sectors—including the transportation, water, and power sectors—and outlined a "flexible" adaptation strategy that requires establishing a communally agreed-upon level of performance for infrastructure as well as identifying climate thresholds at which specific pieces of infrastructure are no longer able to attain this level of performance. The goal of this approach is to maintain flexibility over time so that the best available climate science and design innovation can be used for each infrastructure project. The report recommended several concrete steps such as expanding stakeholder engagement, increasing funding for pre-development analysis to allow for a more thorough exploration of options, and shifting from prescriptive to performance-based standards. It also emphasized the importance of developing skills for decision making under uncertainty. The report identified four common approaches for dealing with uncertainty—scenario planning, robust decision making, adaptive pathways, and flexible design. The core commonality in these approaches is that they select among possible design options by stress testing each design against a range of future conditions, generally selected with extensive public/stakeholder input. The testing process enables engineers to identify vulnerabilities in the designs and then modify them to reduce these vulnerabilities. These approaches diverge significantly from a traditional risk management approach based on known hazard probabilities. Innovative design approaches referenced include "safe-to-fail" design and adaptive design. Safe-to-fail design acknowledges that the risk of failure cannot be eliminated and therefore focuses on reducing the systemic impacts of infrastructure failures. Adaptative design seeks to embed flexibility in infrastructure in a manner that is responsive to changing conditions (e.g.,

floating bridges). These decision-making and design approaches are promising but represent significant deviations from past practices.

While the authors expressed optimism about the capability of engineers and architects to design and construct infrastructure that can accommodate a range of future conditions resulting from climate change, they also identified 11 training and skill gaps that represent barriers to successful infrastructure adaptation (*21*). These barriers, as articulated by the authors, were:

- climate skepticism,
- a lack of understanding of climate science,
- a lack of familiarity with sophisticated risk and uncertainty assessment tools and approaches to decision making under deep uncertainty,
- a lack of familiarity with sophisticated economic analysis methodologies,
- a lack of knowledge of and disconnect from the adaptation literature and field,
- a lack of familiarity with many available tools and platforms,
- a lack of comfort with performance standards,
- a lack of familiarity with adaptive design approaches and techniques,
- a resistance to integrative and systems thinking that crosses silos,
- a lack of skill in effective stakeholder engagement and communication, and
- a lack of cultural competency in working with diverse stakeholders to address long-standing legacies of social exclusion and inequity.

The report noted that prior research has documented that climate change remains largely absent from engineering curricula. It, therefore, calls for widespread workforce development through state agencies, professional societies, and universities that support the "broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context."

In 2017, the Kresge Foundation sponsored a report looking at the state of the climate adaptation field across the United States, drawing on the experience of adaptation "thought leaders," Kresge grant recipients working on climate adaptation, and Kresge staffers (*22*). It is unclear how many of these individuals work directly in transportation, but as stated previously, many climate adaptation considerations are relevant across a wide range of sectors. The report characterized climate adaptation as a nascent field and found that existing adaptation capacity is concentrated in major urban areas since budget constraints and difficulty recruiting, retaining, and training staff present additional barriers to growing adaptation expertise in smaller cities and rural areas. In addition, it found that climate adaptation remains too reactive rather than proactive and that adaptations are rarely implemented outside of the context of post-disaster emergency funding. Overall, the report emphasized the need to rapidly expand adaptation capacity in order to meet the many challenges posed by climate change.

In light of the need for significantly strengthened adaptation efforts, the authors of the Kresge Foundation report attempted to envision what a mature adaptation field would look like based on interviews, surveys, and feedback from professionals with a broad cross-section of adaptation-related experience. This vision included the establishment of rigorous professional standards as well as training and certification opportunities for agreed-upon core concepts and technical skills. A survey of 53 individuals currently working in climate adaptation revealed that no more than one in four respondents believed that there was a well-developed shared adaptation knowledge base (21%) or a well-developed set of standard adaptation practices (25%). Only 4% of respondents considered the funding and policy environment for adaptation to be well developed. Survey respondents were divided not just about the current status of adaptation as a field but also whether or not there should be a separate adaptation field at all—with a group of respondents suggesting that adaptation needs were so deeply enmeshed in other sectors and fields that adaptation could not or should not be considered a separate field but rather needed to be integrated into existing areas of expertise. The report identified several "critical needs" that need to be met to advance climate adaptation in the United States. Specific areas that were identified as requiring improvement included tools and expertise to make the economic case for adaptation, climate risk assessment and disclosure, and concrete measurement metrics of adaptation progress.

While the report noted a growing array of tools to assess climate adaptation options, it also raised concerns that there are no current systems for evaluating, maintaining, and updating these tools, making it difficult for adaptation practitioners to select among these tools and devote the time required to learn how to use them. Improved certification and training options are also needed with a clear educational and professional pipeline for future adaptation professionals. Overall, the authors assessed that the field is currently improving through peer-learning networks but that it needs considerable professionalization as well as better tools and expertise for analyzing and communicating the economic case for adaptation, assessing risk, and measuring progress towards adaptation goals.

Collectively, the FHWA's adaptation initiatives, our prior research including the CAP survey, and reviews by the state of California and the Kresge Foundation paint a broadly consistent picture of the challenges that inhibit successful, widespread climate adaptation in the infrastructure intensive sectors such as transportation. Needs identified across multiple sources are categorized in Table 1. Overcoming these needs on a large scale will require significant additional funding, on-going research and tool development, and extensive workforce development.

Table 1. Climate adaptation needs

Funding and Organizational Capacity	Increased funding and staff time for adaptation initiatives Improved collaboration with outside agencies and climate scientists A better understanding of approaches for decision making under uncertainty throughout the planning and design processes Broadened integration of adaptation principles across agency functions and practices
Research and Tools Development	Greater consensus/guidance on standard adaptation practices Guidance on the selection of emission scenarios and the acquisition and use of highly resolved, local climate projections Development, dissemination, and acceptance of adaptation performance metrics
Workforce Knowledge, Skills, and Abilities	Improved literacy in basic climate science, local climate trends, and climate modeling Expanded capacity for culturally competent stakeholder engagement Greater proficiency with risk and criticality assessment Expanded expertise with benefit-cost and other economic analysis tools to support the case for adaptation and selection/prioritization of adaptation options Improved capacity to evaluate and select among a growing proliferation of adaptation tools Systems thinking

Climate Adaptation Training Needs and Opportunities Survey

Needs and Opportunities Survey Design and Implementation

In order to identify the adaptation-related professional development/training needs and opportunities that already existed at state DOTs and other transportation agencies, the project team developed and administered an online survey for DOTs and regional transportation agencies. Survey respondents were asked what climate threats impacted their region and whether or not training opportunities related to climate and extreme weather adaptation were important for their agency's success. Those respondents who indicated that adaptation training was important for their agency's success were then asked which branches within their agency would benefit from such training opportunities, whether training was currently being offered to those branches, and how such training was being delivered (either externally or in-house at the agency) if it was being offered. In addition to these close-ended questions, respondents were given an open-end opportunity to provide feedback about what adaptation-related resources they had found most helpful and any other information about adaptation planning needs and opportunities at their agency or other transportation agencies that they felt was important. The full text of the survey is provided in Appendix A. The survey was developed and administered in LimeSurvey and was active for 3 months from mid-December 2017 through mid-February 2018. The purpose of this survey was to identify leaders in both adaptation training and adaptation practice as well as to begin to document the pathways available for acquiring these adaptation-related skills for professionals working with in-state and regional transportation agencies.

The survey used a "snowball" recruitment method, where invitees were provided with an unrestricted link to the survey and encouraged to share it with others in their networks who were knowledgeable about climate adaptation efforts. Consistent with the goals of the survey, this recruitment strategy is intended to generate responses from professionals who are active in this field of work and thus potentially represent the leading edge in the field. The initial survey invitations were distributed through several channels. First, an email invitation was distributed through the Nation Transportation Training Directors (NTTD) listserv. Next, the survey invitation was distributed to a list of personnel at MPOs using contact lists developed for prior work in this area (*10*). Finally, postcard invitations to participate in the survey, which included both a survey URL and QR code, were distributed at the 2018 Transportation Research Board Annual Meeting.

Needs and Opportunities Survey Results

In total, respondents from 32 transportation agencies completed the survey, consisting of seven respondents from state DOTs, 24 respondents from MPOs or Councils of Government (COGs), and one respondent from a port authority. For the sake of brevity, the MPO/COG and port authority respondents will be referred to as regional agencies for the balance of this white paper. Unlike the earliest climate adaptation efforts, which were heavily oriented toward sea level rise and coastal flooding (see, e.g., the FHWA's first round of adaptation pilot projects (*23*)), the Needs and Opportunities Survey respondents represented a mixture of both coastal and interior jurisdictions. The locations of the responding agencies are shown in Figure 1.

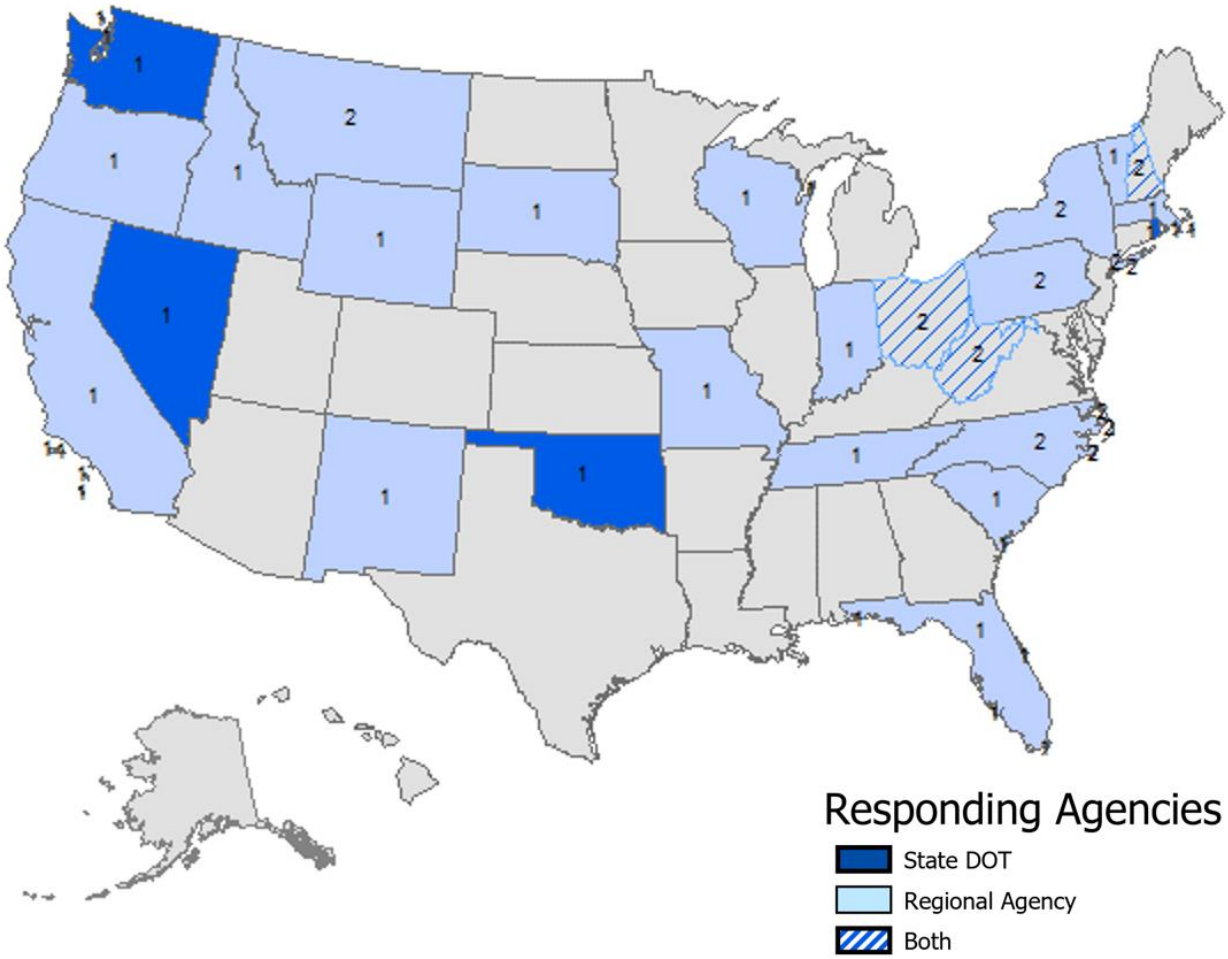

Figure 1. Climate Adaptation Training Needs and Opportunities Survey respondents by state

All respondents were asked whether or not climate adaptation training was important to the success of their agency as well as to identify which of 13 climate trends (enumerated in Figure 2) threatened the integrity of the transportation system in their region. A total of 17 respondents indicated that adaptation training was important for their agency. As might be expected, these respondents identified more climate trends that threatened the transportation infrastructure in their regions than those who indicated that adaptation training was not important or that they were unsure of its importance. It is noteworthy that all respondents, including those who did not believe adaptation training was important to the success of their agency, identified at least one climate-related threat to the transportation infrastructure in their region. The 17 respondents that indicated that adaptation training was important to their agencies identified an average of 5.9 climate threats in their region, with a minimum of two and a maximum of 10 threatening trends identified. The remaining 15 respondents identified an average of 3.2 climate-related threats, with a range from one to eight threatening trends identified in their region. Table 2 provides a cross tabulation of the number of threats identified by agency type and by the respondents' assessment of the importance of adaptation training. As shown in the table, respondents' assessments of the importance of adaptation training and

the number of climate-related threats in their region were broadly consistent between DOTs and regional agencies.

Table 2. State DOT and regional agency assessments of adaptation training importance

Adaptation Training Important	State DOTs				Regional Agencies			
	Number of Agencies	Climate Threats Identified			Number of Agencies	Climate Threats Identified		
		Avg	Min	Max		Avg	Min	Max
Yes	4	5.5	3	8	13	6.0	2	10
No	2	2.0	2	2	6	2.3	1	4
Unsure	1	4.0	4	4	6	4.3	1	8

The specific climate trends that pose the greatest threat to transportation infrastructure vary regionally and with local geography. Figure 2 shows the number of agencies that identified each of the 12 climate trends as a threat to the transportation infrastructure in their region. Hydrologically related trends (flooding, precipitation changes, and erosion) were the most commonly identified threats. Unsurprisingly, given the location of the respondents, none of the survey respondents indicated that thawing permafrost was a threat in their region, but all of the other climate threats were selected by at least three agencies. Also reflective of the geography of the responding agencies, sea level rise was identified as a threat by fewer than 20% of respondents, marking a sharp contrast with the earliest climate adaptation efforts.

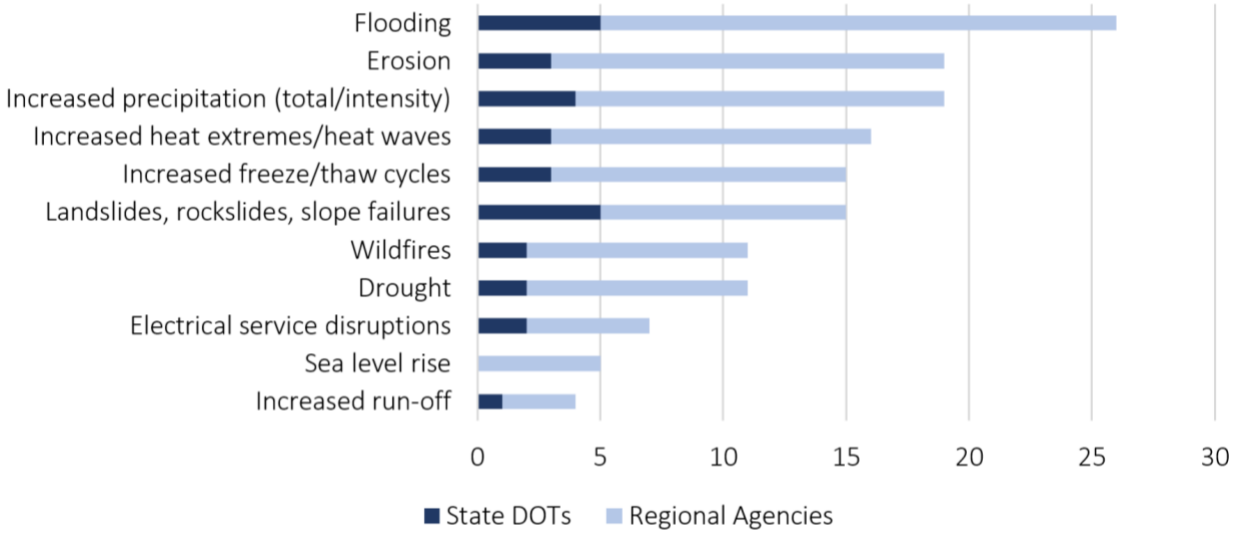

Figure 2. Climate trends threatening transportation infrastructure

As discussed in the Background section, climate adaptation requires integration across many agency functions (and indeed across multiple agencies). To assess where within their agencies state DOTs and regional agencies saw a need for adaptation workforce development opportunities, the 17 respondents who identified adaptation training as important to their agency were asked which of nine agency branches (enumerated in Figure 3) would benefit from

adaptation training opportunities. Consistent with the broadly integrated vision of the climate adaptation process articulated by the FHWA, each of the agency branches included in the survey was selected by a minimum of five survey respondents. The 17 respondents identified an average of 4.6 branches as benefiting from adaptation training. Figure 3 shows the breakdown of the branches within each agency that respondents identified as benefiting from training opportunities related to climate adaptation. All but two respondents identified Planning as a branch that would benefit from such training, and all but four identified Policy and Administration. Seven to nine agencies identified Engineering/Design, Safety, Operations, TSMO, and Communications as branches that would benefit from training, while Budgeting/Procurement and Maintenance were each identified by five respondents. Notably, there is a split in the relative frequency with which state DOTs and regional agencies select different branches as benefiting from training, reflecting the different roles that DOTs and regional agencies play in managing the transportation system.

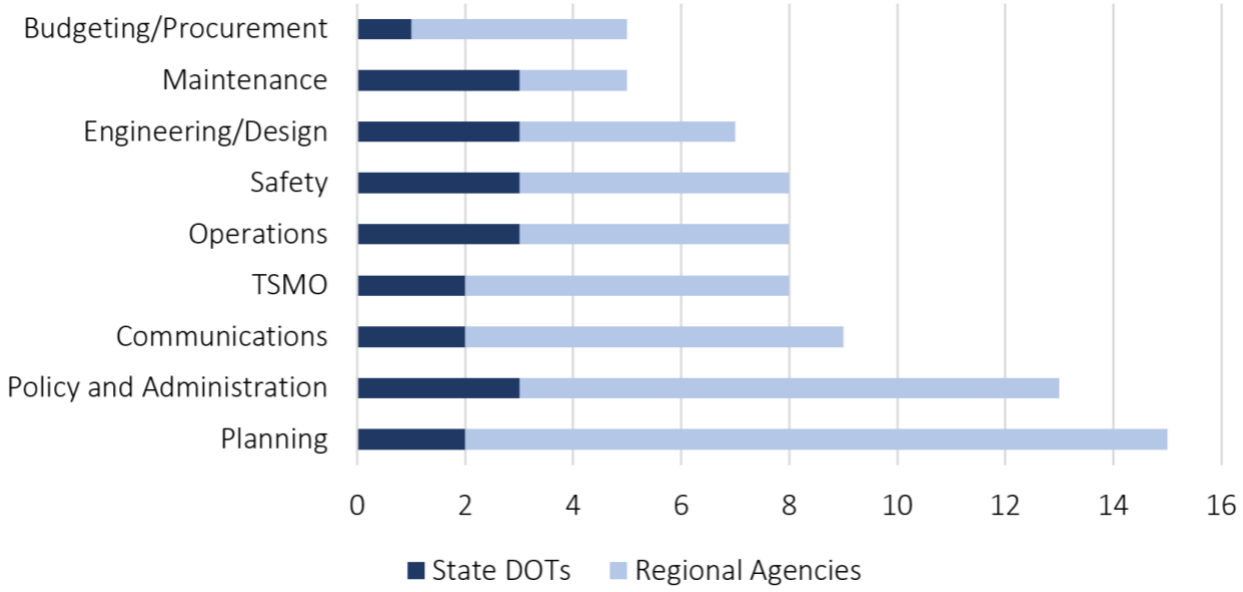

Figure 3. Branches that would benefit from climate adaptation training opportunities

While respondents identified that training would be beneficial for a cumulative total of 78 branches across 17 agencies, current training opportunities were much more limited. Only seven agencies—two state DOTs and five regional agencies—indicated that their agency currently offered adaptation training opportunities to at least one of their branches. Adaptation training opportunities were available to a total of 17 branches across these seven transportation agencies. The status of training opportunities for each of the 17 agencies indicating adaptation training was important is summarized in Figure 4. Crucially, while current training opportunities are limited relative to current training needs, training is available for each of the nine branch types. This indicates that the development and implementation of adaptation-related training are underway across a wide range of transportation functions, though these materials may not yet be standardized or widely disseminated.

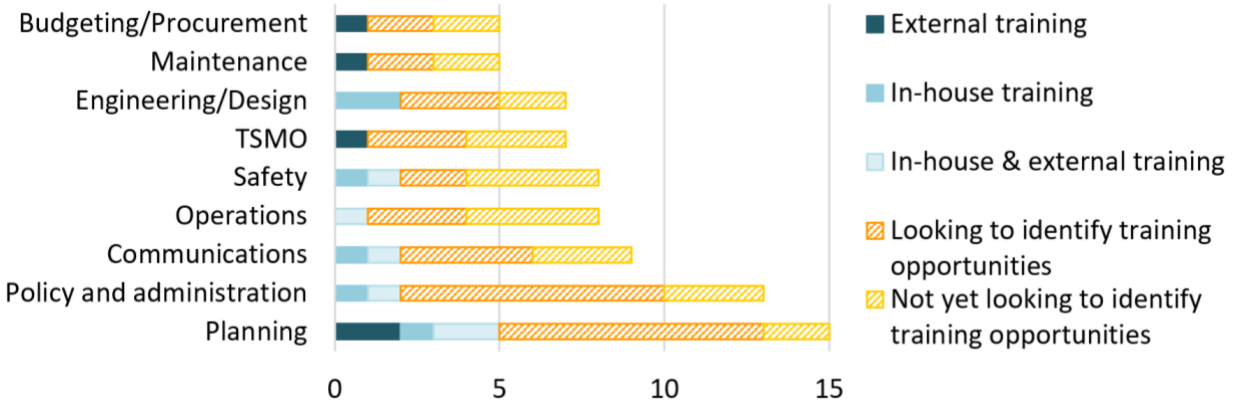

Figure 4. Status of current climate adaptation training opportunities

Open-ended feedback provided by survey respondents placed a heavy emphasis on the importance of sharing methods and resources within and across jurisdictions. Two respondents at agencies that were not yet providing training commented on the value of documenting what trainings have been successful in other jurisdictions, especially where there is cultural resistance to change. Other respondents emphasized the importance of having opportunities for improved inter- and intra-agency communication and coordination, information sharing, and breaking down traditional silos.

Overall, the Needs and Opportunities Survey results indicate a significant, and as yet largely unmet, need for adaptation-related training across transportation sector branches. It should be noted that since the survey invitation was distributed using an open survey link, the eventual survey respondents filled differing roles at different agencies; moreover, the assessment of whether or not adaptation training was important may have varied if other agency personnel had responded to the survey. It is plausible that agency staff who viewed climate adaptation as an important priority would have been more likely to respond to the survey than those who did not. Nevertheless, the survey results indicate a recognition of the need for an agency-wide effort to successfully undertake climate adaptation.

American Society of Adaptation Professionals Mentorship Program

ASAP is a professional society with a mission to connect individuals working on climate change adaptation across sectors and geographic regions to promote information sharing, best practices, and professional development. In the spring of 2017, ASAP launched the Emerging Resilience Professionals Mentorship Program to connect early-career adaptation professionals with more experienced ASAP members. As part of its mentorship program, the ASAP asked applicants to complete a mentee profile prior to and a short survey after participating in the mentorship program. The initial in-take profile asked applicants to list two to five goals related to:

1. improved content knowledge ("understanding of climate science", "details of FEMA funding requirements", etc.),
2. improved technical/professional skills ("how to create a social marketing plan", "how to do a vulnerability assessment", etc.),
3. networking connections ("meet others who are implementing municipal climate resilience plans", "connect with hiring managers at The Nature Conservancy", etc.), and
4. career management ("advice for pathways leading to senior leadership positions", "understanding opportunities in the private consulting sector", etc.).

In addition, applicants were asked to indicate the degree with which they agreed with several statements related to their own technical skills and professional development opportunities. These statements included:

1. I have the technical understanding and skills to successfully complete my job.
2. I know where to access data, information, and other resources on resilience to successfully complete my job.
3. I have access to professional development opportunities that are relevant to my career goals.
4. I know what type of jobs and careers that are available in the resilience field.
5. I have access to information about job openings in the adaptation and resilience field.
6. I have strong role models in the adaptation and resilience field.
7. I have mentors in the adaptation and resilience field.
8. I have a network of colleagues in the adaptation and resilience field that provide me support.

In total, 47 applicants completed the survey in the winter of 2018. Before beginning the mentorship program, 42 of the respondents indicated that they planned on pursuing a career in an adaptation or resilience-related field. Five were working on adaptation/resilience-related projects but were unsure if they would continue to pursue a career in that area. The respondents included graduate students at both the Masters and Doctoral level, as well as current professionals. The majority of professionals participating in the mentorship program worked in the government (Federal, state, and local) and nonprofit sectors. Many but not all

participants either studied or worked in transportation or planning fields. The home states of the program participants are shown in Figure 5.

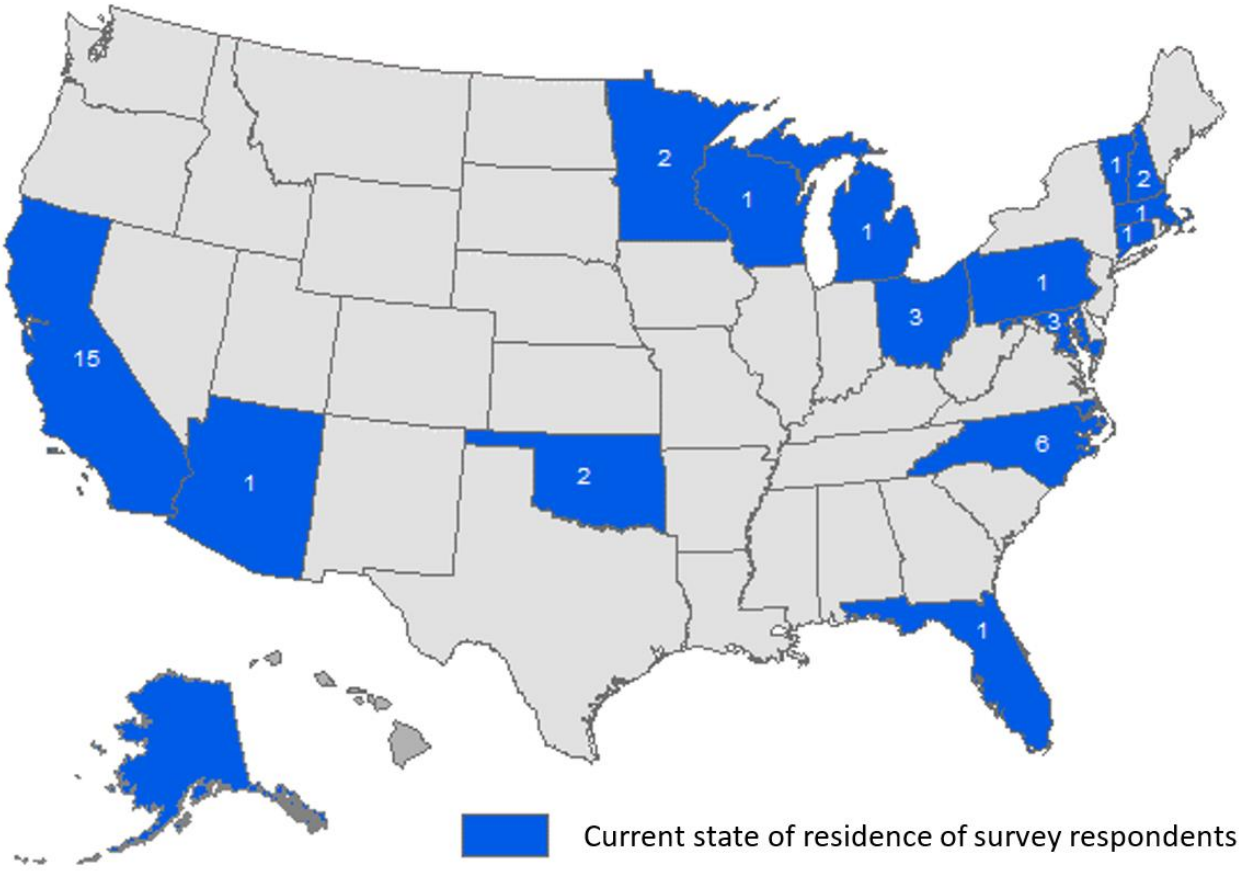

Figure 5. ASAP survey respondents by state

Analysis and Results

Each mentee provided two to five goals, in an opened-ended format, related to improved content knowledge and improved technical/professionals skills. The mentees provided a total of 150 goals related to improved content knowledge and 139 goals related to improved technical skills. In order to facilitate the identification of patterns and commonalities across respondents, the authors coded each of the open-ended goals related to improved content knowledge and improved technical/professional skills into a set of broader categories (seven related to improved content knowledge and six related to improved technical skills). The results of this analysis are discussed in the Mentee Goals section below. The mentee self-evaluation section describes program participants' own rating of their own competencies and confidence in their career pathways after the completion of the mentorship program.

Mentee Goals Related to Improved Content Knowledge

The goals related to improved content knowledge were assigned to seven overarching categories: funding/policy environment, climate science, adaptation strategies, communication/community engagement, adaptation implementation, and best practices. Each category included between three and five subcategories. An overview of the types of goals assigned to each category as well as examples of the goals assigned to each category and subcategory are provided below. The total numbers of goals related to each category and subcategory are shown in Table 3.

Funding/Policy Environment

Forty-one goals were related to the funding/policy environment for adaptation projects. Goals in this category focused on gaining an improved understanding of how to fund adaptation and/or recovery projects as well as what legislative or regulatory requirements governed these kinds of projects. Examples of funding goals included how to obtain planning ("improved knowledge of the resources available to assist in the development of an adaptation planning effort"), implementation ("knowledge of climate adaptation funding mechanisms"), and recovery funding—largely focused on Federal Emergency Management Agency (FEMA) and National Flood Insurance Program (NFIP). Policy environment goals ranged from a broad understanding ("understanding of current and upcoming policies/legislation") to the highly specific ("learn more about US Army Corps project evaluation process and how they are thinking about green infrastructure").

Climate Science

Twenty-two goals were related to improved understanding of climate science. These responses were divided among goals that focused on more general information about climate change and those that indicated an interest in more technical details of climate modeling. The former included a desire to learn more about climate science fundamentals ("improve general understanding of climate science") as well as improved knowledge about on-going climate trends ("understanding climate science trends that are noted in multiple regions."), while the latter focused on interpretation and downscaling climate-related models ("understanding of probabilistic projections of climate impacts" and "downscaling models").

Adaptation Strategies

Twenty-one goals pertained to understanding current adaptation strategies, that is, specific actions that can be implemented to improve resilience. The Adaptation Strategies category was distinguished from the Adaptation Implementation category, described below, by a greater focus on *what* can be done rather than *how* to make it happen. Adaptation strategy goals were related to issues of land use and smart growth ("how land use development tools can be used to help mitigate natural hazards," "zoning for floodplain management"), flooding, and sea level rise ("climate-adaptive flood resilience planning in different contexts"), and green/traditional infrastructure ("details of nature-based solutions and how they can be used to achieve

adaptation goals") as well as a general understanding of adaptation strategies ("learning more about various adaptation strategies").

Adaptation Ecosystem

Fifteen goals were related to understanding where different sectors and agencies plug into the climate adaptation process. Goals included a better understanding of what groups are providing leadership ("who is the leader in the Midwest for resiliency planning"), and how different sectors can/should engage in the adaptation process ("understanding the role of the private sector in recovery and building resilience", "understanding planning and partnership consideration of cities"). This category has some similarities to the Funding/Policy Environment category, as goals in both categories were related to understanding and navigating the larger systems that shape opportunities for climate adaptation. Goals in this category tended to have a broader systems focus, while those in the Policy category focused more on the regulatory environment.

Communication/Community Engagement

Seventeen goals were related to communicating about climate change ("science communication best practices for a public audience") and how to involve stakeholder groups ("perspective of appropriate partnerships that strengthen capacity of under resourced communities," "learn participatory techniques for community engagement and research"). Communication-related goals were also common in response to the technical/professional skills question, as discussed in the next section.

Adaptation Implementation

Fourteen goals were related to *how* to ensure that adaptation strategies could be implemented. Goals in this category included those related to how to integrate adaptation into to existing processes and frameworks ("learn about opportunities for incorporating resilience planning into infrastructure planning"), how science can influence policy ("translating climate science to climate policy"), and how policy can be translated into practice ("ways to implement self-sufficiency, resiliency plans in urban areas").

Best Practices

Fourteen goals were related to best practices in climate adaptation. This category included an emphasis on comparative approaches to climate adaptation ("knowledge of effective climate adaptive infrastructure and programs") as well as general appeals for best practices ("best practices, guidelines").

Table 3. Categorization of goals related to improved content knowledge

Funding/ Policy Environment	**Total**	**41**
	Adaptation Funding Resources	17
	Existing Adaptation Policy/Practice	15
	Recovery Funding Resources (FEMA/NFIP)	9
Climate Science	**Total**	**22**
	Climate Modeling	10
	General Knowledge of Climate Science	8
	Climate Trends, Hazards, & Risk Levels	4
Adaptation Strategies	**Total**	**21**
	Land Use/Zoning/Smart Growth	7
	General	5
	Flooding/Sea level Rise	5
	Green Infrastructure	3
	Infrastructure	1
Adaptation Ecosystem	**Total**	**15**
	Role of Private Sector	7
	Role of Governments	5
	Leaders	2
	Role of Non-profits	1
Communication/ Community Engagement	**Total**	**17**
	Social Justice	7
	General Engagement	6
	Communicating Hazards	3
	Youth Engagement	1
Adaptation Implementation	**Total**	**14**
	Process Integration	4
	Policy to Practice	4
	Policy Making/Advocacy	3
	Science to Policy	2
	Prioritization	1
Best Practices	**Total**	**14**
	Best Practices - General	8
	International Practices	2
	Best Practice - State & Regional	2
	General Resources	2

Mentee Goals Related to Improved Technical/Professional Skills

The goals related to improved technical/professional skills were assigned to six overarching categories: assessment, communication and community involvement, adaptation planning and

evaluation, data visualization/mapping, funding, and project management. Each category included between three and five subcategories. The total numbers of goals related to each category and subcategory are shown in Table 4. Assessment, specifically the subcategory of vulnerability assessment, was the single most common goal related to skill improvement ("how to do a (participatory) vulnerability assessment").

Table 4. Categorization of goals related to improved technical/professional skills

Assessment	**Total**	**33**
	Vulnerability Assessment	22
	General	3
	GHG Inventory	2
	Risk Assessment	2
	Cost-Benefit	2
	Market Analysis	1
	Environmental Impact	1
Communication & Community Involvement	**Total**	**30**
	Science to Public	11
	Engagement	6
	Facilitation	4
	Social Media	3
	General	3
	Policy Advocacy	2
	Vulnerable/Marginalized Populations	1
Adaptation Planning and Evaluation	**Total**	**28**
	Adaptation Plan	13
	Integrate Adaptation into Other Plans/Practices	5
	Metric Selection, Monitoring, and Evaluation	4
	Climate Action Plan	3
	Plan to Practice	2
	Social Justice	1
Data Visualization/ Mapping	**Total**	**13**
	GIS	5
	Visualization	4
	Flood Modeling	1
	Climate Modeling	1
	Other Software	2
Funding	**Total**	**12**
	Grant Writing	5
	Agency Funding	5
	Climate Finance	2
Project Management	**Total**	**9**
	General	3
	Budgeting	2
	Program Design	1
	Leadership	1
	Data Management	1
	Assess Success	1

Mentee Self-Evaluation

Many of these respondents expressed uncertainty about how to move forward within adaptation/resilience-related careers. As shown in Figure 6, fewer than half of the respondents agreed that they knew what types of careers were available to them, had access to relevant professional development goals, and had strong role models in adaptation and resilience fields. No more than 10% of respondents strongly agreed with any of these statements. Respondents expressed the most significant disagreement with the statements that they had strong adaptation role models, 44% somewhat or strongly disagreed, and that they knew what adaptation jobs and careers were available, 40% somewhat or strongly disagreed.

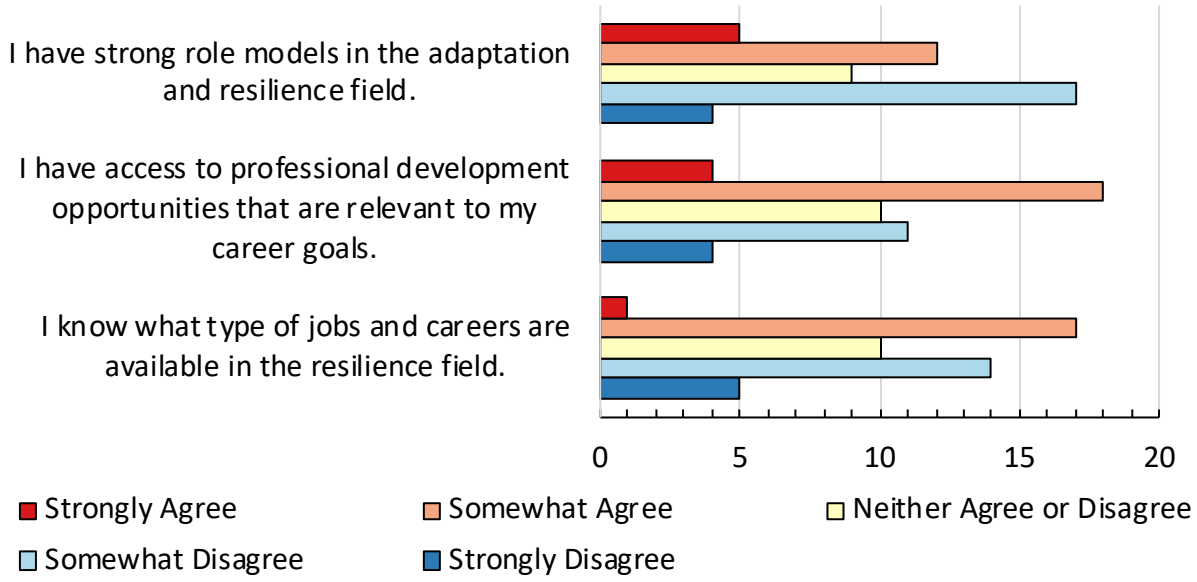

Figure 6. Mentee confidence in career advancement opportunities and resources

While many respondents expressed some degree of uncertainty about resources for career advancement, they generally expressed greater confidence in their own skills and competencies. When asked about their own competencies, 79% percent of the respondents somewhat or strongly agreed that had they had the technical skills and ability to access the resources required to successfully complete their jobs.

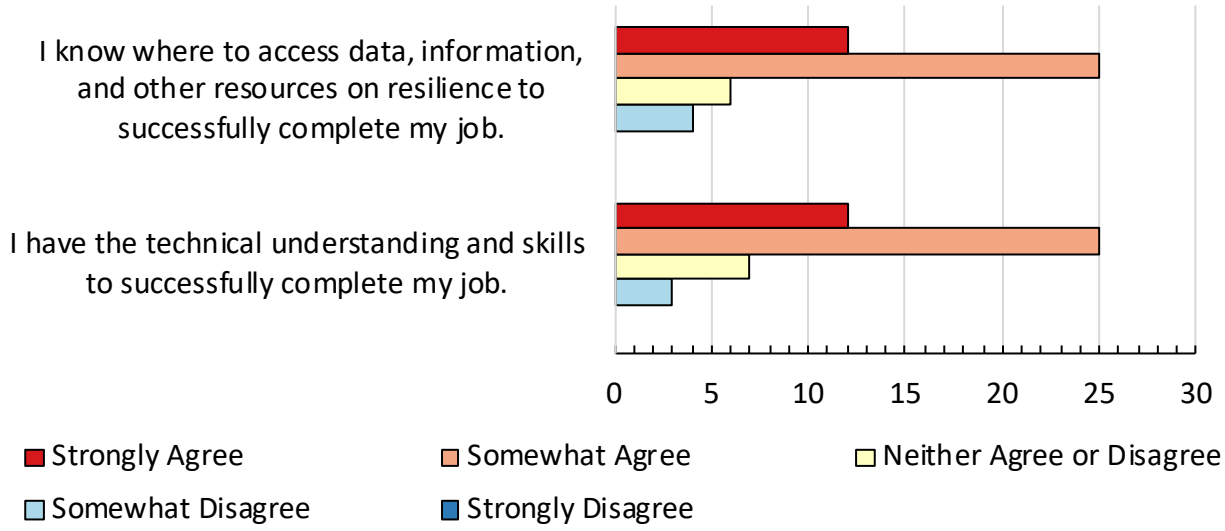

Figure 7. Mentee confidence in data accessibility and technical knowledge

Overall, the data collected in conjunction with the ASAP mentorship program show the need for professional development opportunities for aspiring adaptation professionals. Participants in the mentorship program likely represent some of the individuals most qualified and highly motivated to work in this area. These individuals expressed a desire for a wide range of improved content knowledge related to the environment in which climate adaptation must take place, including where to find funding and how agencies and sectors collaborate. In addition, these aspiring professionals want greater information about what strategies work and how to get them implemented. Skills related to vulnerability assessment, communicating science to the public, and creating adaptation plans were also highly sought after.

There is a substantial degree of overlap between the knowledge and skills sought by the ASAP mentees and the needs identified in the background section of this white paper. Climate science literacy and the use of climate model outputs, understanding adaptation options, communication with stakeholders, integration of adaptation into agency practices to ensure implementation, and identifying funding mechanisms for adaptation are prominent issues for agencies engaging in climate adaptation as well as for aspiring adaptation professionals. Mentees place a greater emphasis on understanding the structural and policy environment for adaptation as well as the broader strokes of the adaptation process, while agencies may be focused on more specific barriers within the process. This is not unexpected given that mentees are early-career professionals and agency professionals are already experienced in some of these areas. Indeed, one of the benefits of mentorship programs like that of ASAP is to facilitate this kind of knowledge transmission between more experienced adaptation professionals and those just entering the field. These sources point to a largely consistent set of workforce needs for adaptation professionals.

Scan of Higher Education Programs and Professional Societies Related to Climate Adaptation

Going forward, expanding adaptation workforce capacity will require on-going training and professional development for current professionals as well as adaptation-centered programs in higher education to prepare future professionals for adaptation careers. Results from the Training Needs and Opportunities Survey and the ASAP mentorship program indicate that there is an appetite for adaptation-related training and professional development among both transportation sector employers and potential employees. In this section, we provide a preliminary scan of graduate-level degree and certificate programs in climate adaptation and discuss the alignment between the courses required for these programs and the training needs identified in the prior sections. In addition, we provide a brief discussion of the activities of two adaptation-focused professional societies—ASAP and the Association of Climate Change Officers (ACCO).

A preliminary search for current Climate Adaptation programs at colleges and universities in the United States surfaced eight climate adaptation degree and certificate programs affiliated with departments of planning (2), engineering (2), sustainability (2), earth science (1), and geography (1). Based on program and course descriptions at the institution's website, we assessed that these programs address many of the core climate adaptation needs identified in the prior adaptation initiatives reviewed in the background section and by applicants to the ASAP mentorship program. As shown in Table 5, all eight of these programs offer courses that teach adaptation strategies, and six require climate science or natural hazards courses. Climate communications, policy and funding, and scenario planning or decision making under uncertainty are explicit focuses of four of the programs. A brief description of each of these programs and examples of the core courses associated with each are provided in Table 6.

Table 5. Key learning areas in climate adaptation programs

	Antioch	Carnegie Mellon	NC State	UMass Amherst	Idaho	Chapel Hill	USF	Utah State
Adaptation Strategies	X	X	X	X	X	X	X	X
Climate Science	X	X	X	X	X	X		
Communication	X		X	X				X
Funding/Policies	X		X				X	X
Scenario Planning/ Decision Making Under Uncertainty		X	X	X				X

Overall, course work offered through these programs aligns relatively well with the needs identified through the other data sources examined for this white paper. These programs are all relatively new, however, and remain relatively small in number, indicating the need for growth in this area. Note that the programs discussed here were identified through an internet search for "climate adaptation degree" and "climate adaptation certificate." These results do not

represent a comprehensive catalog of such programs, but they do provide an overview of the types of programs that are currently available to potential students interested in climate adaptation. Our focus was on programs that emphasize climate *adaptation* specifically; therefore, these results do not include many programs on climate change science, sustainability, community leadership, or environmental justice even though graduates of these programs may end up working on climate adaptation issues. Additionally, these results are limited to colleges and universities in the United States. A broader selection of universities with sustainability offerings can be found through the Global Council for Science and the Environment (GCSE).

In addition to these higher education programs, professional societies for climate adaptation professionals are emerging and offering growing support for on-going professional development. These include ASAP, which was founded in 2011, as well as the ACCO, which was founded in 2008.

As described previously, ASAP's mission[1] is to connect adaptation professionals across regions and disciplines to advance adaptation practice. In addition to its mentorship program, ASAP conducts a range of networking activities, organizes member-led working groups, provides microgrants to support collaboration, hosts a curated adaptation job board, and has developed a range of adaptation resources including a code of ethics, a "Living Guide" on adaptation principles, and a framework of knowledge and competencies.

The ACCO's mission[2] is to develop resources to support organizational leadership to address climate-related risks. The ACCO offers a number of online training modules in areas ranging from climate risk and adaptation planning through economics and project finance and offers a "Certified Climate Change credential" that is geared to mid-level adaptation professionals. In addition to ASAP and the ACCO, which are organized around the issue of climate change, a variety of disciplinary professional societies are beginning to address climate issues with their members. The activities of 41 of these organizations were cataloged by the Kresge Foundation in 2017, which found that the American Planning Association, American Institute of Certified Planners, American Society of Landscape Architects, and American Society of Civil Engineers were offering training related to climate adaptation (24).

[1] https://adaptationprofessionals.org/about/#mission-and-history
[2] https://climateofficers.org/whoweare

Table 6. Higher Education Climate Adaptation Programs in the United States

Institution/Program	Description	Example Courses
Antioch University - New England: Environmental Studies and Sustainability	Antioch University offers a nine-credit Climate Resilience Certificate that is geared toward current professionals. It is intended to enhance the adaptation skills of individuals working in community planning, hazard mitigation, and other fields.	Climate Change: The Science, Uncertainty, and Risk Climate Impacts: Vulnerability & Adaptation Planning Climate Impacts: Communication & Facilitation Business Resilience and Continuity Climate Justice and Equitable Adaptation Climate Response Climate Resilience Certificate for Professionals: Capstone
Carnegie Mellon: Center for Engineering & Resilience for Climate Adaptation (CERCA)	CERCA faculty members offer "a suite of integrated courses to prepare the next generation of engineering students for leadership in climate change adaptation." It supports a concentration in Climate Change and Adaptation for Infrastructure for Masters students in the Department of Civil and Environmental Engineering.	Climate Science and Policy Climate Science and Adaptation International Climate Adaptation & Infrastructure Innovation Climate Change Adaptation for Infrastructure Urban Systems Modeling
North Carolina State University: Climate Change and Society Program	NC State's Department of Marine, Earth, and Atmospheric Sciences offers a four-class Climate Adaptation Certificate as well as a one-year Master's Degree that blends policy, communication, and fundamental climate science courses for students interested in climate adaptation in wide variety fields.	Fundamentals of Climate Change Science Climate Risk Analysis for Adaptation Barriers to Climate Change Literacy Introduction to Geographic Information System Science
UMass Amherst: Department of Landscape Architecture and Regional Planning	The Department of Landscape Architecture and Regional Planning offers a five-course certificate in Climate Change, Hazards, and Green Infrastructure Planning. This certificate aims to "bring together planning and design" and equip "students with a highly sought after and unique skillset in one of the most pressing topic areas in policy today."	Planning for Climate Change Green Infrastructure Intro to GIS Adapting to Climate Change Urban Greening Cultural Heritage and Climate Change

Institution/Program	Description	Example Courses
University of Idaho: Department of Geography	The Department of Geography at the University of Idaho offers a four-course Climate Change certificate for students interested in both climate adaptation and climate mitigation. The certificate is intended to improve climate literacy across disciplines.	Global Climate Change Climatology Climate Change Ecology Climate Change Mitigation Geography of Energy Systems Societal Resilience and Adaptation to Climate Change Climate Change and Society
University of North Carolina: Department of City and Regional Planning	The Department of City and Regional Planning offers a certificate in Natural Hazards Resilience that trains "researchers and practitioners who can help the public, non-profit, and private sectors become more resilient in the face of natural hazards and disasters and adapt to the effects of a changing climate."	Planning for Natural Hazards & Climate Change Adaptation Survey of Natural Hazards and Disasters
University of South Florida: College of Global Sustainability	The College of Global Sustainability offers both a Master's concentration and certificate program in Climate Change and Sustainability. The certificate is a four-course program focused on "the development of an analytical perspective ... on climate change, climate vulnerability, adaptive capacity and pathways of climate adaptation/resilience."	Concepts and Principles of Sustainability Economics and Finance for Sustainability Climate Change Adaptation and Mitigation Policy for Sustainability
Utah State University	Utah State University offers a Climate Adaptation Science specialization in conjunction with 11 Masters and ten Doctoral programs. The specialization "integrates training in informatics, modeling, communication, leadership, project management, risk assessment, decision-making under uncertainty, and interdisciplinary teamwork." It emphasizes hands-on experience to prepare graduates for careers at the nexus of climate science and management and is part of the NSF Research Traineeship (NRT) program.	Climate Adaptation Sciences Interdisciplinary Research Colloquium Climate Adaptation Science Studio Climate Adaptation Science Internship Science Communication Capstone

Conclusions

Climate adaptation is now a well-documented need in the transportation sector, and there are strong conceptual frameworks for the adaptation process. Implementation of adaptation processes requires significant changes to traditional practices within transportation agencies. Adaptation places a greater imperative on collaboration across agencies and agency functions and will require professionals with a broader set of proficiencies than have been historically necessary. The development of the adaptation workforce is still in the early stages, but the increased value placed on adaptation-related expertise by DOTs and regional transportation agencies as well as the emergence of new educational and training opportunities in climate adaptation available in higher education and professional organizations is indicative of the potential for rapid growth in this area.

Across past and ongoing adaptation initiatives, surveys of transportation agencies and aspiring adaptation professionals, and current adaptation offerings in higher education, there is evidence of convergence on the areas of content knowledge, technical expertise, and soft skills that form the core competencies necessary to support climate adaptation within the transportation sector. As noted in the CSIWG report (*21*), developing adaptation capacity will generally require a more expansive set of skills and expertise to enable collaborative processes that put the design and management of the transportation system in the larger environmental, social, and economic context necessary to support equitable and effective adaptation efforts. These core competencies are in:

- **Climate Science**: A basic understanding of climate change and local climate trends needs to be embedded throughout transportation agencies. At the most basic level, this helps staff understand the broad pattern of climate threats in their region that will inform almost all aspects of agency operations. A more advanced understanding of climate science and climate modeling facilitates the successful, in-depth collaboration with climate modelers that may be necessary to obtain and understand high-quality, localized, climate forecasts with actionable spatial resolution.
- **Adaptation Strategies**: A general understanding of the strategies that can be used to reduce climate risk also needs to be present throughout transportation agencies. As demonstrated in the Adaptation Training Needs and Opportunities survey and other work, most agency functions are or will be impacted by climate change. A broad understanding of how to respond to these impacts needs to be widely available, while a more detailed understanding of specific strategies, ranging from procedural changes in maintenance and options through long-term relocation of transportation assets and flexible design approaches, needs to be concentrated within different agency branches.
- **Communication**: Communication skills take on an outsized role in many components of the climate adaptation process. These skills are necessary for managing climate skepticism inside and outside transportation agencies, making the case for adaptation funding, engaging stakeholders in scenario planning and complex conversations about risk, and promoting collaboration across traditionally siloed disciplines.

- **Selection and Prioritization of Adaptation Measures/Decision Making Under Uncertainty**: One of the greatest challenges in adapting to climate change is the considerable and inherent uncertainty in the magnitude of future climate change and climate change impacts. This uncertainty means planners and engineers must consider a range of possible extremes while designing the transportation system rather than designing for a known and relatively static set of weather conditions. This requires stress testing designs against a range of future extremes, looking for design options that maintain future flexibility, and engaging stakeholders to determine a societally acceptable balance of risk and cost. In this context, scenario planning, tools for understanding asset criticality in the context of complex network dynamics, economic analysis, and life-cycle assessment as well as innovative engineering practices are all needed to ensure that a full range of adaptation options are considered and that project selection and prioritization are equitable and effective.

While these competencies need to be broadly distributed throughout transportation agencies, the relative emphasis placed on each competency will vary across agency functions and job responsibilities. Future research on climate adaptation workforce needs should work to delineate the degree of understanding and specific proficiencies required in each of these core areas for planners, engineers, asset managers, and operations and maintenance personnel. Such a mapping could help to inform job seekers about the skills that they should be looking to acquire, to shape the educational offerings of university and professional societies, and to ensure that hiring and training decisions at transportation agencies support the growth of climate adaptation capacity. Specific research initiatives to support this mapping should include a) a more compressive assessment of how climate adaptation is (and is not) incorporated into two and four-year degree programs, b) focus groups or interviews with agency staff that have led adaptation initiatives to better understand the specific proficiencies required within different agency branches, and c) a similar effort with private sector firms active in climate adaptation.

Several immediate actions are also available to current transportation agency leaders and policymakers. Leaders have the opportunity to:

- Continue building support and recognition of the importance of climate adaptation within their agencies and jurisdictions. More than 45% of agencies that responded to the Needs and Opportunities Survey did not believe that adaptation training was important to the success of their agency, and many of the initiatives reviewed for this white paper also cited climate change skepticism as a barrier to adaptation initiatives.
- Prioritize broad-based training in climate literacy and region-specific climate threats. Embedding an understanding of local climate threats and how this impacts agency operations throughout an agency will empower staff across agency divisions to engage proactively with the challenges of climate adaptation.
- Provide resources and time to support staff in pursuing additional training opportunities.

- Incorporate the climate adaptation core competencies identified above into new hiring decisions, especially for planners and engineers.

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Data Management

Products of Research

The project team developed and administered the Climate Adaptation Training Needs and Opportunities Survey to assess the status of adaptation-related professional development at state DOTs and other transportation agencies. Survey respondents were asked what climate threats impacted their region and whether or not training opportunities related to climate and extreme weather adaptation were important for their agency's success. Those respondents who indicated that adaptation training was important for their agency's success were then asked which branches within their agency would benefit from such training opportunities, whether training was currently being offered to those branches, and how such training was being delivered (either externally or in-house at the agency) if it was being offered.

The survey used a "snowball" recruitment method, where invitees were provided with an unrestricted link to the survey and encouraged to share it with others in their networks who were knowledgeable about climate adaptation efforts. Consistent with the goals of the survey, this recruitment strategy is intended to generate responses from professionals who are active in this field of work and thus potentially represent the leading edge in the field.

The survey was developed and administered in LimeSurvey and was active for 3 months from mid-December 2017 through mid-February 2018. In total, respondents from 32 transportation agencies completed the survey, consisting of seven respondents from state DOTs, 24 respondents from MPOs or Councils of Government (COGs), and one respondent from a port authority.

Data Format and Content

Two files relating to this survey were produced: a spreadsheet with all survey results (n=32) and a PDF file of the survey instrument (also in Appendix A of this document).

Data Access and Sharing

De-identified survey results and a copy of the survey instrument are available on the Dryad data repository website at https://doi.org/10.5061/dryad.s7h44j15k.

Reuse and Redistribution

The data from the Needs and Opportunities Survey are accessible to the public and open for reuse and redistribution with appropriate citation:

> Dowds, Jonathan; McRae, Glenn (2020), Climate Adaptation Training Needs and Opportunities Survey Dataset, https://doi.org/10.5061/dryad.s7h44j15k

Appendix A – Climate Adaptation Training Needs and Opportunities Survey

Survey Introduction:

Many transportation agencies are exploring climate/extreme weather adaptation measures to enhance the resilience of the transportation system. This emphasis on adaptation requires new skills and competencies in agency staff.

The University of Vermont is conducting a study to identify core competencies and career pathways for climate adaptation professionals in the transportation sector. This **brief, 10-question** survey is intended to identify adaptation-related professional development/training needs and opportunities at DOTs and other transportation agencies.

Your Agency's voluntary participation in this project is greatly appreciated. Please feel free to share the link to this survey with others within your Agency or at other agencies. To take part in the survey, please review the "Additional Project Information" below and **click the "Start Survey" button at the bottom of this page**. We ask that survey participants provide contact information in case of follow-up questions, but this information is not required to complete the survey.

If you have any questions about this survey, please contact the project Principal Investigator:

Jonathan Dowds

Survey Questions

[Page 1] Agency Information

Agency Type

- State DOT
- Metropolitan Planning Organization (MPO) or Council of Governments (COG)
- County Public Works/DOT
- Municipal/Local Public Works/DOT
- Other (please specify)

Agency Location

[Drop down list of states]

[Page 2] Adaptation Training Needs

Are training opportunities related to climate and extreme weather adaptation important for your Agency's success moving forward?

Select "Yes" if these opportunities are a recognized need at your agency even if you are not yet providing training related to climate adaptation.

1. Yes
2. No {Skip to Page 5}
3. Unsure {Skip to Page 5}

[Page 3] Scope of Adaptation Training Needs

What branches within your agency would benefit from training opportunities related to climate adaptation?

Please select all that apply.

- ☐ Transportation systems management and operations (TSMO)
- ☐ Maintenance
- ☐ Operations
- ☐ Engineering/Design
- ☐ Planning
- ☐ Budgeting/Procurement
- ☐ Communications
- ☐ Safety
- ☐ Policy and administration

[Page 4] Current Adaptation Training Opportunities

How are climate adaptation training opportunities provided for these branches?

Please select all that apply.

{List branches selected on Page 3}

- ☐ Currently offering in-house training
- ☐ Currently supporting external training
- ☐ No training currently offered but looking to identify training opportunities
- ☐ Not yet looking to identify training opportunities

[Page 5] Adaptation Training Resources

{Show only if respondent agency currently offering in-house or external training}

What are the most valuable resources you have found for climate adaptation training?

{Text box}

Approximately how much of your adaptation training is offered online?

- ☐ None
- ☐ Less than 25%
- ☐ More than 25% but less than 50%
- ☐ More than 50% but less than 75%
- ☐ More than 75%
- ☐ 100%

[Page 6] Climate and Extreme Weather Threats

What climate trends and related events pose a threat to the transportation infrastructure in your region?

Please select all that apply.

1. Increased total precipitation or precipitation intensity
2. Flooding
3. Erosion
4. Landslides, rockslides, slope failures
5. Increased heat extremes/heatwaves
6. Increased freeze/thaw cycles
7. Thawing permafrost
8. Increased run-off from changes in snow/glacial melt
9. Sea level rise
10. Drought
11. Electrical service disruptions
12. Wildfires
13. Unsure

[Page 7] Additional Information

Is there additional information about adaptation planning needs and opportunities at your agency or other transportation agencies that you would like to share?

{Text box}

[Page 8] Respondent Information

Contact Information

1. Name: [Text box]
2. Title: [Text box]
3. Agency: [Text box]
4. Email: [Text box]
5. Phone Number: [Text box]

Thank you for taking the time to complete this survey. If you would like to be notified once the final report for this project has been completed, please contact Jonathan.