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Article

Transferring Research Innovations in Bridge Inspection Planning to Bridge Inspection Practice: A Qualitative Study

Abdelrahman M. Abdallah [1,*], Mehmet E. Ozbek [2] and Rebecca A. Atadero [3]

[1] Exp U.S. Services Inc., Miami, FL 33134, USA
[2] Department of Construction Management, Colorado State University, Fort Collins, CO 80523, USA; mehmet.ozbek@colostate.edu
[3] Department of Civil and Environmental Engineering, Colorado State University, Fort Collins, CO 80523, USA; rebecca.atadero@colostate.edu
* Correspondence: rahman.abdallah@exp.com

Abstract: Over the last two decades, many researchers have focused on providing new ideas and frameworks to help improve conventional bridge inspection planning approaches, however, little guidance is provided for implementing these new ideas in practice, resulting in limited change. Accordingly, this qualitative study aims to identify the factors that can help improve research products and accelerate research transfer to bridge inspection departments with the goal of enhancing bridge inspection practice. This study used semi-structured interviews, written interviews, and questionnaires for data collection to provide rich results. Responses from twenty-six bridge personnel from state Departments of Transportation (DOTs) across the United States (U.S.) were included in this study. The study found that most participants support a fixed inspection interval over a variable interval since fixed intervals are easier in scheduling and budget planning. Also, participants indicated that the barriers hindering the use of nondestructive techniques are the training required by inspectors, traffic control, and the required access equipment. The study presents the factors change leaders should focus on to facilitate organizational change in DOTs such as enhancing the capacity of DOT staff members and gaining support from the Federal Highway Administration (FHWA)

Keywords: bridge inspection; qualitative research; research transfer; organizational change; inspection planning

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1. Introduction

Bridge inspections are one of the key elements required for a successful bridge management process to ensure adequate bridge performance. Over the last two decades, many researchers have focused on providing new ideas and frameworks that can help improve conventional bridge inspection planning practices, however, very little guidance is provided for implementing these new ideas in practice [1–3]. This lack of guidance, along with resistance to change and the complexity of the proposed ideas, resulted in a lack of consistency and success in applying new innovations and technologies in bridge inspection programs, and how bridge owners adequately plan bridge inspection time and technique. Accordingly, this qualitative study set out to identify the factors that can help improve research products and accelerate change and research transfer in bridge inspection departments with the goal of enhancing bridge inspection planning. This study focuses on providing bridge owners with practical new methods that can help optimize their process in choosing inspection time and method.

In the U.S., routine inspections are the most common type of bridge inspection, and almost all are conducted at least every two years as required by the Federal Highway Administration (FHWA) using mainly visual evaluation [4]. The limitations of current inspection practices have been documented in several studies, and a variety of improvements have been proposed by researchers to improve inspection scheduling, inspection techniques, and management of inspection data [5]. However, despite these research efforts and their potential to improve inspections' value and reduce costs, Departments of Transportation (DOTs) and the FHWA still depend on conventional inspection methods. Therefore, the objective of this research study is to engage with DOT bridge staff members to answer three research questions:

1. What do bridge inspection professionals think about current bridge inspection practices and how they can be improved in the USA?
2. What are the actions that can help improve the applicability and practicality of research products in the bridge inspection field and other DOT engineering applications in the USA?
3. From both human and organizational change perspectives, what factors should be considered to accelerate the implementation of research in bridge inspection practices in the USA?

This study used semi-structured interviews, written interviews, and questionnaires for data collection to provide rich results. Twenty-six bridge staff members from different DOTs, with different managerial levels and responsibilities were involved in this study. To develop our data collection methods, a literature review was conducted on three major topics: bridge inspection, research transfer, and organizational change. Data analysis was conducted using a thematic framework, and research findings were presented accordingly.

Our study distinctively bridges the gap between innovative research proposals and their practical implementation in bridge inspection programs. By not only emphasizing new techniques but also the organizational and human factors pivotal for change, our research brings a fresh perspective to the challenges faced in the bridge inspection domain. Furthermore, by involving diverse DOT staff and utilizing a comprehensive data collection approach, we ensure that our findings resonate with the realities of the field, setting our work apart in its depth, relevance, and applicability.

2. Background

The framework of this study draws from the fields of bridge inspection, research transfer, and organizational change. Thus, this section briefly highlights some of the significant findings of the literature review that helped in developing the study approach and data collection methods.

2.1. Bridge Inspection

This study focuses on bridge inspection because it is a field where significant limitations have been identified with current practices, and despite a variety of research products proposed to address these challenges, the field has seen only limited change. During routine inspections, inspectors are exposed to risks of injury due to limited accessibility and mobility in some locations [6]. Inspectors' qualifications and training may significantly vary, which can affect the quality of the reported inspection data [7]. Further, general and subjective visual inspections are limited to surface defects and are associated with a high level of uncertainty [8]. Also, the 24-month inspection cycle specified for routine inspections does not consider the condition of the bridge or the in-service environment and can lead to delayed or necessary inspections impacting the bridge performance or wasting inspection resources [9]. Research to enhance bridge inspections has focused on developing new inspection scheduling frameworks, such as reliability and risk-based frameworks [9,10], implementing nondestructive evaluation (NDE) methods [11] and drones [12], and developing new software and database management systems that can enhance the inspection management process [13]. This study investigated participants' opinions of the conventional methods used to schedule routine bridge inspections, the barriers to implementing NDE, and how the quality of inspections can be improved in general.

Furthermore, over recent years, technological advancements have significantly transformed bridge inspection planning, providing engineers with tools that not only increase accuracy but also reduce risks associated with manual inspections. One notable development is the deployment of unmanned aerial vehicles (UAVs) or drones for bridge inspections. According to a study by [14] drones equipped with high-resolution cameras and sensors can provide detailed images of hard-to-reach areas of bridges, enabling efficient identification of potential structural issues. This technology minimizes the need for personnel to work in hazardous conditions, thereby increasing safety and reducing inspection times.

However, while these technologies offer significant advantages, their integration into routine bridge inspection practices is not without challenges. Practical hurdles such as regulatory constraints, the requirement for skilled operators, and concerns over data privacy can impede widespread adoption. Additionally, while UAVs provide detailed visual data, interpreting this information requires expertise, emphasizing the importance of a harmonious blend of technology and human judgment. Thus, while technologies like drones hold promise for revolutionizing bridge inspection planning, their pragmatic application necessitates a nuanced understanding of both their capabilities and limitations [15].

The planning phase of bridge inspections has always been critical, as it dictates the efficiency, safety, and thoroughness of the entire process. Recent advancements in technology have introduced tools like data analytics and predictive modeling to enhance this planning stage. Advanced analytics, driven by the integration of geographic information systems (GIS) and machine learning (ML), allow agencies to optimize inspection schedules based on real-time traffic data, environmental conditions, and historical bridge performance. For instance, ref. [16] highlighted the role of visual data and ML in forecasting bridge deterioration, enabling timely planning of inspections. These tools aid in predicting which parts of a bridge may be prone to defects or damage, allowing inspectors to prioritize and allocate resources effectively. However, while these predictive tools bring significant potential, they rely heavily on the quality and comprehensiveness of the data they are fed. Therefore, successful bridge inspection planning with these technologies requires robust data collection systems and continuous training to interpret and act on the predictive insights accurately.

In the rapidly evolving landscape of bridge inspection planning, emerging technologies such as predictive analytics, GIS integration, and machine learning present transformative possibilities. While these tools offer the potential to greatly enhance planning efficiency and accuracy, understanding their real-world applicability and integration challenges is essential. Our qualitative study seeks to bridge this gap. By engaging directly with bridge inspection professionals, we aim to capture the nuanced perspectives, insights, and potential barriers faced when integrating these cutting-edge tools into everyday practices. Through in-depth interviews and thorough analyses, our research provides a unique lens into the practical implications, readiness, and organizational considerations pivotal for the successful adoption of these technological advancements in bridge inspection planning.

2.2. Research Transfer

Strategies to improve research transfer are evident in the literature from different scientific fields. Thus, this section reviews the problems researchers, sponsors, and practitioners in different domains face while implementing new research findings. Then the strategies that can help overcome these challenges and can be applied in the transportation sector are identified. A common finding is that research implementation strategies are not cheap and require resources and enough time to ensure a successful transition process [17].

In the transportation community, many studies are conducted by the National Cooperative Highway Research Program (NCHRP) to help disseminate new research findings, enhance the responsiveness of transportation research programs, and build a standard practice for research implementation throughout the whole field [18]. The NCHRP is focusing on providing effective research products, and implementation frameworks and enabling implementation cultures in transportation organizations [19]. Several key players have been involved in those studies such as the Transportation Research Board (TRB), the American Association of State Highway and Transportation Officials (AASHTO), state DOTs, and the FHWA [18]. Some of the research efforts have been presented in transportation conferences and guides published by the NCHRP [20–23]. Also, the Strategic Highway Research Program 2 (SHRP 2) has been one of the national examples of commitment to funding and providing expertise for research implementation. The SHRP 2 has allocated a USD 75 million budget to help support research transfer in the highway sector [24]. At the state level, the state planning and research federal aid has specified 4% of its budget for accelerating research implementation in DOTs as part of the Moving Ahead for Progress in the 21st century (MAP) [21]. Additionally, DOTs such as Pennsylvania DOT have developed a group consisting of diverse local stakeholders responsible for tracking and evaluating new innovations that can help the DOT, while allocating the necessary resources to facilitate the implementation process [25].

In the extensive body of literature addressing the integration of research into practice, several barriers consistently emerge, often rooted in both systemic and operational dimensions. One of the foremost challenges, as articulated by [26] lies in the inherent gap between the academic research environment and the field of professional practice. Academia frequently values novelty, theoretical rigor, and comprehensive analyses, often resulting in outcomes that, while robust, may be perceived as overly complex or esoteric by practitioners [26]. On the other hand, professionals in the field prioritize solutions that are immediately applicable, cost-effective, and straightforward to implement. This divergence in priorities often results in what [27] termed the "relevance gap," where findings from research, despite their potential, remain underutilized or misunderstood.

One of the main barriers to research implementation is depending on a single individual or champions to lead change and not having a systematic implementation process managed by a qualified team of implementation experts [18]. Currently, some organizations such as the Federal Aviation Administration (FAA) are using research transition teams responsible for implementing new research ideas, connecting researchers with practitioners and sponsors, and mitigating barriers during the transition process [28]. Also, producing guides and clear policies for research implementation practices can help in documenting and assessing the implementation process. The National Oceanic and Atmospheric Administration (NOAA) continuously updates its policy on research and development transition, to guide researchers and developers to identify the necessary steps to implement new technology into practice and gain all the required permits [29].

Transitioning research findings to actionable practice in real-world scenarios presents distinct challenges, often stemming from the controlled environments in which research typically operates. Sutherland et al. [30] highlight that while research aims for clarity and precision within these isolating environments, the application of these findings is often muddied by the unpredictable variables of real-world contexts, potentially diminishing the research's efficacy. To further complicate matters, premature deployment of nascent technologies can stymie effective technology transfer, as outlined by [31]. In response to such challenges, it becomes paramount to employ structured frameworks to ensure a technology's readiness for real-world application. A notable example is NASA's technology readiness level scale, which provides a systematic evaluation ensuring that innovations are mature and apt for deployment [32].

Additionally, there is the economic aspect of integrating research into practice. Implementing novel methodologies or technologies often demands significant financial investment, be it in new equipment, training, or restructuring of existing frameworks. This barrier was one of the main aspects discussed in this research paper and identified by participants as the most predominant barrier to change. For many organizations, especially those operating on tight budgets such as DOTs or in competitive markets, such expenditures can be prohibitive. Furthermore, the return on investment (ROI) for adopting new research findings might not be immediately apparent or quantifiable, leading to decision-making that favors short-term economic gains over long-term benefits that research integration might offer [33].

Another prominent challenge lies in the dissemination and accessibility of research findings. Academically rigorous research is often published in journals that, while prestigious, may be inaccessible to practitioners due to paywalls or specialized jargon. This can lead to a lack of awareness among potential beneficiaries of the research, thus hindering its adoption. Moreover, the sheer volume of research being produced can be overwhelming, making it challenging for practitioners to sift through and identify the most relevant and recent findings applicable to their context (Spector, P. E., 2021). This information overload, coupled with the potential lack of synthesis or meta-analyses that distill the essence of multiple studies into actionable insights, further stymies the effective application of research in practice. Further, managers who control budgets and critical decisions in an industry do not have enough time to read through whole journal articles or research proposals [34]. Therefore, to accelerate research implementation, the Department of Agriculture developed the Joint Fire Science Program (JFSP) [34]. This program focuses on collecting data from the literature and publishing systematic reviews and synopses that are concise and accessible to managers in the industry.

Moreover, organizational barriers further compound these challenges. Institutions, be they academic or industrial, often operate in silos, creating logistical and communicative barriers to effective knowledge transfer [35]. Such silos may limit opportunities for collaborative engagement, further widening the gap between research and practice. The rapid pace of technological advancements further exacerbates this issue. As scholars rush to explore the next frontier of innovation, there is a risk that the resultant knowledge becomes quickly outdated, or that the tools and technologies required for implementation become obsolete before they see widespread adoption in the field [36] In this evolving landscape, it becomes evident that a multi-pronged approach addressing both organizational and operational barriers is essential for bridging the research–practice divide.

2.3. Organizational Change

Transitioning to new research methodologies and frameworks necessitates an evolving mindset and, often, a significant overhaul of the prevailing culture within DOTs [21]. One of the most profound challenges this transition faces is deeply rooted in the phenomenon termed "cognitive inertia". As articulated by [37], after investing years in perfecting and internalizing existing methodologies, organizations become heavily anchored to their current practices. This attachment, driven by cognitive biases and compounded by the inherent risks perceived in embracing change, manifests as resistance to innovative paradigms. Overcoming such inertia does not merely entail the assimilation of novel concepts. It equally underscores the essential, albeit psychologically challenging, process of unlearning entrenched beliefs and practices that have become obsolete in the face of new evidence and advancements.

In our comprehensive exploration of this topic, we zeroed in on a myriad of factors and models that promise to facilitate the organizational change process, especially the ones that proactively address and diminish resistance [38]. This deeper understanding not only served as a foundational pillar while addressing our third research question but also enabled us to engage in rich discussions with participants. Gleaning insights from their lived experiences with organizational change, we sought to validate the efficacy of the change drivers identified in scholarly literature, particularly in the context of DOTs. Furthermore, this comprehensive perspective on organizational change furnished us with a clear roadmap, directing us toward key stakeholders whose insights and experiences would be indispensable for a holistic and diverse understanding of the topic at hand.

Initiating a successful transformation hinges on two primary actions: recognizing the imperative for change and performing a thorough analysis of the prevailing situation [39]. For organizations, especially within the public sector, having an intricate and robust planning process becomes indispensable. This planning should be supported by meticulously defined goals and coherent policies, ensuring that the entire organization is aligned, and reducing potential inconsistencies or misinterpretations among decision-makers [40]. External dynamics, especially those shaped by overarching policies and regulatory environments, exert a profound influence on organizational strategies and actions [41]. Yet, it is essential to remain vigilant, as in environments dense with policy directives, there is a risk that decisions may lean towards symbolic gestures, valuing form over substantive transformation [42]. Meyer and Rowan [43] further reinforce this notion, suggesting that organizations might, at times, gravitate towards policy adoption for optics and perceived legitimacy rather than driving genuine, efficacious change.

Effective organizational change hinges on aligning transformational processes with the people's capabilities and values to mitigate resistance [44]. Ensuring involvement across hierarchical levels, particularly human resource professionals, is essential for a seamless transition [45]. Amplifying this, recent studies emphasize the paramount importance of employee well-being during pivotal shifts, with [46] underscoring the role of "psychological safety". Creating such environments bolsters engagement and reduces resistance. Similarly, [47] advocate for a holistic approach, highlighting that considering the entirety of employee well-being is a cornerstone for successful organizational evolution.

In the complex realm of organizational change, the role of leadership becomes paramount. Leaders who are deeply committed to the change process, and who lead by example, can act as catalysts, galvanizing the entire organization towards the desired transformation [40]. More than just steering the ship, these leaders ensure clear and effective communication across all levels, fostering an environment of inclusivity and understanding. Their influence extends to stabilizing the organization post-transition, ensuring that the strategic goals set at the outset are not only achieved but also sustainably integrated into the organizational fabric [48].

In recent times, the discourse on organizational change has witnessed an infusion of digital dimensions. As the digital landscape evolves at an unprecedented pace, leaders are now expected to be proficient not just in traditional leadership skills but also in digital literacy. Cortellazzo et al. [49] have emphasized the emergence of "Digital Change Leaders"—leaders who deftly blend foundational leadership principles with an adept understanding of the digital realm. Such proficiency ensures that organizations are not merely reactive to technological innovations but are proactively positioned to leverage these advancements. Adding depth to this perspective [50] introduce the concept of "Organizational Digital Resilience". In an era marked by rapid technological advancements and equally swift disruptions, institutions need to intertwine resilience into their digital strategies and culture, ensuring they are equipped to both harness the potential of emergent technologies and navigate the intricacies of the digital age.

Economic constraints have been consistently recognized as pivotal determinants in the success and trajectory of organizational change. According to [51] in their article "Cracking the Code of Change" in the Harvard Business Review, there are two main paths of corporate change: the economic-focused "Theory E" and the organizational-focused "Theory O". While "Theory O" centers on the development of corporate culture and human capabilities, "Theory E" underscores the economic value and the critical role financial performance plays in driving change. However, economic constraints can stifle "Theory E" approaches, as limited resources might force organizations to curtail or adjust their ambitions. Such constraints can hinder critical investments, from infrastructure to human resources training, essential for change initiatives [39]. Furthermore, in his work "Leading Change," Kotter posits that a lack of resources can undermine efforts at establishing a sense of urgency, a critical first step in his eight-stage process of creating major change.

Smith [52] commented that the major reason behind failure in organizational changes is the initiation of a change without having enough resources and trained manpower to sustain this change, which is found in our study as one of the main challenges DOTs face when incorporating new bridge inspection planning approaches. Also, [53] found that allowing enough time for staff members to adapt to a new technology is important to reduce resistance and relax the implementation of the new technology. Kotnour [54] found that having a well-defined change management model, that is systematic and suited to organizational change goals, will lead to a smooth transition. Several change models have been presented in the literature with systematic steps to facilitate organizational change [39,55].

3. Methodology

To address the specific research questions and given the practical and exploratory nature of this study, a qualitative research method was selected that includes interviews and questionnaires.

3.1. Participants

Staff members in public organizations can perceive innovation and change differently depending on their positions and responsibilities [40]. Accordingly, we aimed for a maximum variation sample [56] of key personnel in the organizational structure of state departments' bridge management divisions with the following criteria:

- Level 1 (L1): A program manager responsible for approving new inspection techniques, new funding, hiring consultants, research, communicating with the FHWA, and deciding on training programs for inspectors.
- Level 2 (L2): A team leader in the DOT's inspection team, decides on the number of inspectors, type of inspections (in-depth or routine), time and method of inspection, and uploads reports to the state's bridge management system.
- Level 3 (L3): A bridge inspector in the DOT, conducts the bridge inspection and prepares the inspection report.

The goal of the sampling approach was to fully identify how different managerial levels and staff members could contribute to research implementation and organizational change. The participants were either involved in the change planning phase, execution phase, or both. It should be noted that these job descriptions are generic and different states might arrange responsibilities differently. Also, the title of each job position can differ depending on the department of transportation, however, responsibilities can be the same.

3.2. Data Collection

Following an approved Institutional Review Board (IRB) protocol, an email was sent to participants asking them to participate in our study and telling them the reason they were chosen and the possible risks and benefits. To obtain rich answers to our research questions, the investigation protocol consisted of four main data collection methods: "Bridge Inspection Questionnaires", "Journal Article Interviews", "Organizational Change Interviews" and "Written Interviews". The data collection process started in November 2020 and ended in May 2021. All interview questions were sent to participants before the interviews. Two researchers were present in all interviews, which were conducted in a private setting with participants, either using video conference or telephone conference due to the COVID-19 pandemic. Also, to broaden the range of viewpoints and to make sure that participants are answering questions related to their responsibilities, each data collection method involved at least two different job levels (L1, L2, and/or L3).

3.2.1. Bridge Inspection Questionnaires

The first step to implementing change and innovation in organizations is to analyze the current situation and the changes required [39]. Therefore, the Bridge Inspection Questionnaires (shown in Appendix A) were developed to gather information about current inspection practices, how DOTs plan and conduct inspections, and what participants think can help improve current inspection practices. The questionnaires were self-administered and consisted of six open-ended questions. The Bridge Inspection Questionnaires were emailed to L2 and L3 participants only. The questionnaire was specifically directed toward L2 and L3 participants due to its technical focus on on-site inspection challenges and nuances. L1 participants, primarily overseeing program management, typically do not engage directly in on-the-ground inspections, making the questionnaire's detailed items less directly relevant to their roles.

3.2.2. Journal Article Interviews

To generate rich data from interviews, especially the ones discussing broad topics, investigators need to build their discussions on examples or scenarios that make sense to interviewees or are related to their field of expertise [57]. To do so for this study, the participants received by email three journal articles [9,58,59] that discuss three different strategies for bridge inspection planning. With this approach, the goal was to use the inspection planning frameworks proposed in the articles as examples of research products the DOT bridge staff members can relate to and discuss with participants their opinions on each article. Also, in the Journal Article Interviews, the authors discussed with participants some of the important aspects related to current inspection practices such as the 24-month inspection cycle and using NDE methods during inspections. The interviews were 45 min and semi-structured to provide the same basic interview structure for all participants but allow participants to add additional information during the interview and allow researchers to ask follow-up questions. Only L1 and L2 staff members were involved in the Journal Article Interviews. L1 and L2 participants were exclusively engaged with the journal articles due to their expertise and aptitude in analyzing research publications. The research team had concerns that L3 participants, based on their specific experience, might not possess the depth of understanding required to critically evaluate the articles. Appendix B shows the questions that were asked during the Journal Article Interviews

3.2.3. Organizational Change Interviews

According to [60], designing a successful change framework starts by analyzing the views of those who have previously experienced change in their organization. Therefore, in the semi-structured Organizational Change Interviews, participants were asked about their past experience with organizational change and the factors they think can facilitate change and research transfer in bridge inspection divisions. Appendix C shows the questions that were asked during the Organizational Change Interviews. The questions tried to analyze if the participants agree with the factors mentioned in some of the theoretical change models and if there are other factors DOTs need to be aware of. This part of the study was also 45 min but included all levels of participants, to understand how different staff members in the organizational hierarchy perceive change.

3.2.4. Written Interviews

As the study progressed, it became apparent that tight schedules and lack of time for employees working in the DOTs made it difficult to schedule phone or video interviews. Accordingly, to increase the number of participants a written format (Written Interviews) of the most critical questions from other data collection methods was prepared. The Written Interviews shown in Appendix D consisted of mostly open-ended questions and were sent to participants who the authors believe are L1 and L2 employees in different state DOTs. Responses to the Written Interviews were anonymous, so the authors cannot state for certain that only L1 and L2 employees responded.

3.3. Response Rate

Seventy-three DOT staff members were contacted, however, a total of twenty-six DOT staff members participated in this study (the response rate is equal to 35%) consisting of nineteen anonymous participants, three L1 managers, two L2, and two L3 staff members. Table 1 summarizes the number of participants involved in each data collection method.

We gathered 19 written responses from L1 and L2 participants that served as the core data for our study. Scheduling constraints restricted our ability to hold live interviews with participants from L1 to L3. Nevertheless, we believe that the feedback from L1 and L2 participants is particularly valuable. Both L1 and L2 participants engage in and supervise inspections, managing teams that comprise L3 members. As a result, their perspectives play a pivotal role in our conclusions. In this study, the qualitative methodological approach was intentionally employed to delve deep into the perceptions, experiences, and suggestions of bridge inspection professionals, rather than to achieve statistical generalizability. While the sample of 26 participants might not represent the entirety of bridge inspection professionals in the U.S., it was strategically chosen to capture diverse insights from various geographical locations and backgrounds. This rich assortment ensured the emergence of comprehensive themes, with data saturation being achieved, a key milestone in qualitative research. Nevertheless, readers should interpret the findings with an understanding of the depth-oriented nature of qualitative research. The insights garnered offer a profound understanding of the participant perspectives but may not encapsulate every viewpoint from the broader population of bridge inspection professionals nationwide.

Table 1. Data collection methods and participants involved.

Method	Purpose	Participants
Bridge Inspection Questionnaires	Gather information on current inspection practices	Two L2 and two L3
Journal Article Interviews	Discuss the three journal articles and some aspects related to current practices such as the 24-month inspection cycle and NDE methods	Three L1 and two L2
Organizational Change Interviews	Discuss factors related to organizational change	Three L1, two L2, two L3
Written Interviews	Contains some of the critical questions in other data collection methods such as: (1) 24-month inspection cycle, (2) risk-based inspection (3) organizational changes needed to facilitate innovation in DOTs, (4) how to improve inspection quality, (5) how to speed research transfer in the inspection industry	Nineteen anonymous L1 and L2 participants

3.4. Data Analysis

Interview data were transcribed and analyzed along with the participants' written responses using thematic analysis [61]. Minimal edits were conducted on extracts to enhance readability, without changing the meaning or inference. The analysis started with the researchers familiarizing themselves with the data, then establishing initial codes, themes, and subthemes, reviewing, and organizing themes and subthemes, and finally presenting the results. Participants' responses were initially read by the first author and iteratively coded using inductive coding to identify ideas emerging from the data, together with deductive coding based on literature review to address the research questions. All authors were included in each stage of the analysis process and frequent meetings before and after reaching data saturation were conducted to discuss themes and ideas, resolve converged or diverged interpretations in our respective analyses, and make sure the research questions were being answered. Forms of triangulation were conducted on parts of the data involving all three authors to enhance credibility and dependability [56]. For some of the interviews that were not allowed by participants to be recorded, the authors engaged in a member check to reach consensus agreement on the key findings and ensure accuracy of the data collected [56].

4. Findings and Discussion

Based on the participants' responses across all four data collection methods, five main themes were identified in the data: (1) the 24-month inspection cycle, (2) evaluating bridge performance, (3) the effectiveness of research products, (4) change barriers, and (5) change facilitators. In response to the first research question, themes 1 and 2 demonstrate participants' opinions on some of the important aspects related to current inspection practices such as the 24-month inspection cycle used to schedule routine inspections and the tools used in evaluating bridge performance. Theme 3 presents what participants suggested can help improve research products, which was our goal in the second research question, while themes 4 and 5 helped us answer our third research question regarding the factors that can help facilitate change and research implementation. Figure 1 illustrates the identified themes, the ideas or subthemes they present, and how themes or subthemes provide a secondary contribution to answering other research questions.

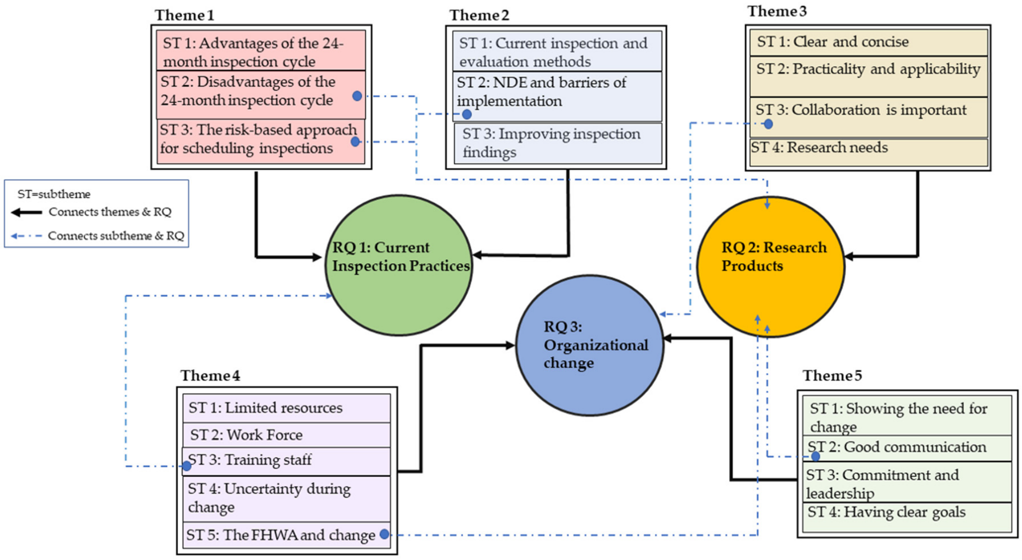

Figure 1. Themes and subthemes and their connection to the research questions.

Our results and discussions are carefully segmented into themes that directly respond to the proposed research questions. For the first question on bridge inspection practices, the themes "The 24-Month Inspection Cycle" and "Evaluating Bridge Performance" offer an in-depth look into prevalent procedures, juxtaposing real-world methods with academic perspectives, emphasizing both the merits of the fixed interval and the critical need for advanced nondestructive evaluation (NDE) techniques. Addressing the second question on enhancing research applicability, the "Effectiveness of Research Products" theme casts light on the gap between academic discoveries and their on-the-ground application, accentuating the necessity for research that aligns closer with practitioners' needs and underscores collaboration. Finally, for the third question concerning factors for organizational change, the themes around "Change Barriers and Facilitators" provide a comprehensive overview of the complexities in implementing research-driven practices in DOTs, underscoring the pivotal roles of communication, leadership, training, and resource management. Each theme is thus sculpted to not only present data but to synthesize practitioner insights with scholarly literature, delivering actionable strategies essential to the bridge inspection realm.

4.1. Research Question 1: Current Inspection Practices and Areas for Improvement

Theme 1: The 24-Month Inspection Cycle

Much of what was discussed with participants regarding current inspection practices was related to the 24-month inspection cycle and the methods used to conduct inspections. All participants confirmed that they follow a fixed interval of 24 months for routine inspections and sometimes this interval can be shortened to 12 months if the bridge is structurally deficient, while in other cases the inspection interval can be extended to 48 months if the structure is in good condition and after approval of the FHWA. During our analysis of the literature, it was found that many researchers argue against the 24-month inspection interval [9,62]. For example, [9] stated that the uniform inspection cycle does not consider how bridges can be different in age, condition, environment, or construction material, and accordingly this fixed approach does not utilize inspection resources efficiently. Also, [62] concluded that the fixed inspection cycle can lead to unnecessary inspections for many bridges in the National Bridge Inventory. In our investigation, it was found that 24% of the participants agreed with the literature, while surprisingly 44% of participants supported the 24-month inspection cycle, and the remaining 32% stated that it has some advantages and some disadvantages. The participants who supported the uniform 24-month inspection interval stated that it helps in planning inspections, unlike variable intervals: "*Uniform inspection intervals makes setting up inspection schedules, resources and tracking tools somewhat easier as timelines are uniform*" (anonymous participant). Other participants commented on how the fixed interval can help them group bridges together to reduce traveling time and cost: "*Variable frequencies can be a bit of a challenge the most difficult thing is getting to the bridge, we try to group bridges geographically, so if you have a bridge on a 24-month frequency and one on a 36-month frequency it will not make sense to go out to the middle of nowhere to inspect one bridge*" (L2 employee). Participants commented that the fixed interval can help budget inspections, especially for states with a large bridge network: "*I think it is cost effective for big states, a variable inspection schedule will be hard to budget*" (L1 employee). Moreover, participants found that one of the main problems in applying a variable inspection planning framework is managing bridge inspectors since a variable inspection schedule will lead to downsizing or hiring new inspectors, which is not an easy task in public organizations.

From what is available in the literature, it is clear that there is a gap in the field of bridge inspection planning between researchers and practitioners. Some researchers in the field of bridge inspection planning do not consider the impact of the bridge location or the traveling cost on the inspection planning process, and how difficult a variable inspection schedule will be in budgeting inspection costs. However, other researchers have considered bridge locations and the bridge's importance in a whole network when developing maintenance management frameworks [63].

Although most of our participants supported the 24-month inspection cycle, an L2 manager mentioned that the FHWA was pressured by DOTs to allow a different alternative for scheduling inspections such as the risk-based inspection (RBI) approach presented by NCHRP 12-82 [64], so that DOTs can save some resources spent unnecessarily on bridge inspections: "*I think the primary reason is the pressure they have gotten from states, and they are saying ok yes you're convincing us that it isn't always reasonable to use the uniform approach. I think it will happen I am seeing the trend with FHWA going more with risk-based systems with load ratings, and risk-based guidelines; they are going down that road*" (L2 employee). This indicates that there is disagreement among practitioners. For the risk-based approach, 36% of the participants said they would apply it once it is allowed, 21% said they would not consider it, and 43% indicated that they would wait and see how other state DOTs will apply it. A variety of opinions was evident in the participants' comments about the risk-based approach the FHWA is considering to allow as a second alternative for scheduling routine inspections [65]. Some participants found that this approach will help reduce the number of inspections and save resources: "*The number of inspections would be reduced. Therefore, the quality of inspections should improve because our inspectors would have more time to complete them*" (L1 employee). Others were concerned about the time and effort that will be required to set the risk-based inspection planning framework and gather the required data: "*My concern with it is the expert panel, my concern is time and as with a lot of DOTs I think it will be challenging to be able to assemble the group that has the time to go through the structures and figure all of that out. It may be time well spent but sometimes we don't have the luxury of making that decision on our own*" (L2 employee).

Bridge inspection planning is a complex process that involves many variables, such as inspection cost, bridge location, managing traffic and quality of inspection methods, and inspectors. The RBI program discussed earlier in this paper is the first step towards a rational inspection planning process, however, may diverge significantly from traditional, uniform inspection strategies, thus requiring a significant commitment of time and resources to facilitate the change. Researchers can help DOTs implement the RBI program by: (1) defining the scope of the inspection program and the type of bridges that will be considered in the initial implementation phase, (2) streamlining the RBI planning framework and integrating the framework with DOTs' bridge management systems, and (3) optimizing inspection scheduling and logistics by grouping bridges with similar properties and geographical location to minimize costs.

Theme 2: Evaluating Bridge Performance

With regards to the methods used during inspections, participants agreed with what was found in the literature and the NBIS [66], that visual inspection is the main method used to evaluate the bridge performance during routine inspections, and in some cases, a chain drag can be used to detect delamination [7]. Regardless of the limitations and variability of visual inspections proved several times in the literature [67–69], participants used visual inspections to rate bridge conditions, decide on whether the inspection cycle needs to be reduced or not, and even plan for maintenance work.

Due to the limitations of visual inspections, many scholars have suggested the use of other NDE methods [70]. In our investigation, it was found that most participants use NDE methods such as infrared thermography or magnetic particle tests during in-depth inspections or fracture critical inspections, which agrees with the findings of Lee and Kalos [71]. Further, according to [71], the barriers hindering the use of NDE methods in state governments are the capital cost needed to purchase the equipment and the difficulty associated with some NDE techniques. Adding to what [71] concluded, in our study, 26% of the participants mentioned that although NDE methods have the potential to improve inspections they require access to equipment such as snoopers, traffic control, and training and certifying inspectors, which is a huge burden on bridge inspection divisions: "*Skill and training is a big barrier; we need our inspectors to be certified to do NDE. Access can be a challenge too if inspectors see something during routine inspection they may have to come back with a left dropper or a snooper to get close enough to do NDE in those areas, it also requires traffic control*" (L2 employee).

In connection with our main study objective to improve inspections, it was discussed with participants the main aspects that can help improve inspection data. Fifteen out of twenty-six participants mentioned that training bridge inspectors and enhancing their abilities can lead to significant improvements in the value of bridge inspections: "*Most important improvement is training. It helps inspectors understand not only the bridges and how they function, but the reason that they do inspections*" (L2 employee). Lin et al. [68] found that one of the problems affecting the reliability of the data collected during inspections is the quality of bridge inspectors and lack of training. Also, four participants stated that developing clear policies and protocols for bridge inspections can help reduce ambiguity and differences between DOTs, this agrees with what [72] found during their study on the reliability of bridge inspections. To improve the bridge condition assessment process, participants recommended focusing on improving the quality of NDE results and promoting the application of drones (unmanned aerial vehicles) during inspections: "*Using drones to detect fatigue cracks I think that will be the direction, I think we will see more drones in the future*" (L2 employee). Two participants commented on the data collected from drones and NDE, and that research should focus on improving the quality of the output of this equipment and provide frameworks on how to incorporate it into the bridge management process. Also, one participant suggested a relatively interesting idea, which is adjusting inspection efforts depending on the condition of the bridge to reduce inspection effort and time: "*Bridge inspection is complicated. Uniform application of rules to a complex problem may sound inefficient. I suggest determining what level of inspection effort should be spent depending on the bridge condition. For example, a newer or simple structure may take a cursory inspection of key elements, and this could be sufficient to verify if changes to the ratings are necessary. The times saved here should be spent on more complex structures or bridges with poor conditions*" (anonymous participant).

Based on the findings presented, the answer to research question 1, is that bridge inspection professionals predominantly adhere to the standardized 24-month inspection cycle, and opinions about its effectiveness vary. While a significant portion appreciates the regularity of this fixed interval for its advantages in inspection planning, logistical efficiencies based on geographical clustering, and predictability in budgeting, others acknowledge the potential of alternative methods like risk-based approaches. However, there is concern about the feasibility of transitioning to these new methods, with challenges cited such as time and resource commitment to set up the risk-based inspection planning framework.

In terms of assessment techniques, visual inspections remain the cornerstone despite their inherent limitations. While some nondestructive evaluation (NDE) methods find occasional use, practical barriers such as the capital costs of equipment, requisite training, and accessibility challenges prevent their widespread adoption. Nevertheless, the professional community underscores the significance of ongoing inspector training and clearer policies to ensure data reliability. There is also a burgeoning interest in technology-driven methods like drones, suggesting that the sector is open to embracing advancements, provided the existing challenges are adequately addressed.

4.2. Research Question 2: Improving Applicability and Practicality of Research Products

Theme 3: Effectiveness of Research Products

Based on our discussion with participants about the different inspection planning approaches presented in the three journal articles, several participants pointed out that sometimes research products are hard to understand and researchers need to provide clear research results that can be readily understood and applied in practice: "*One of the research papers has stuff that I can use and implement, it might take some time and have to do some allocation of resources, but I can understand it, it is workable, it is like yes this makes sense. While for the other two, at least reading the papers was challenging; it is challenging for me to take that and go over here and use it, I feel there is still a gap here*" (L2 employee). Ref. [73] found that some of the main reasons hindering research implementation in practice are that researchers focus on theoretical or conceptual issues that are impractical or inapplicable, and on the other hand, practitioners do not accept new research ideas that can require change in their daily procedures or industrial traditions.

Also, most bridge inspection managers do not have time to read through long journal articles, therefore research products have to be concise and to the point as Level 1 and Level 2 participants recommended: "*A lot of bridge owners and inspection managers do not have time to read through a research paper to evaluate the findings and its applicability*" (L1 employee). Ref. [74] stated that time constraints can make it difficult for practitioners to read and refresh their knowledge with new research that can be applied in the field. Moreover, participants noted that researchers should not only focus on solving specific problems or providing ideas that can only be applied to specific types of bridges or deteriorations: "*As far as implementing the stuff you guys come up in the lab well some of these ideas are awesome but applying it to thousands of bridges statewide seems impractical*" (L3 employee). Researchers need to provide solutions that can be generalized on different bridges so that DOTs can weigh the costs and apply solutions to several assets.

In this context, to provide effective research products, 70% of the participants suggested working together and collaborating as researchers and practitioners to improve research products and direct researchers' efforts in the right direction: "*The more we can communicate and work together the better off it is going to be for everybody. The people in academia will not feel that they are doing things for no reason, and we are going to feel like, you are going to do things that we understand and need*" (L2 employee). Researchers in the implementation field found that collaboration between academics and practitioners in the industry can significantly improve research results, and speed research and knowledge transfer into practice [75,76]. After studying several case studies in the construction industry, [73] found that using active research techniques enhances collaboration between researchers and practitioners and helps solve some of the important problems practitioners face. Active research is a technique that has been applied in different industries where researchers and practitioners work together to evaluate the current situation and solve immediate practical problems in the industry [73].

In addition, researchers in the bridge inspection field can promote their findings by providing practitioners and state DOTs with summaries of key findings to update them and save their time. These summaries can be presented on platforms where bridge inspection planners and researchers connect and exchange ideas, similar to what was presented by the Joint Fire Science Program (JFSP) [34]. Conferences such as the Transportation Research Board (TRB) can also help gather academics and workers in the industry to discuss important issues in the industry and share successful implementation strategies [21]. To make sure research findings are applicable, researchers in the bridge inspection field can use ideas like the technology readiness scales [32] or product evaluation criteria developed by NCHRP [18]. These techniques can help researchers and DOTs make sure that a research product is fully developed, easy to implement by staff members, feasible, and can be applied to different cases before deployment. DOTs can even hire a single staff member or a research and development team responsible for finding innovative solutions and evaluating their applicability.

In summary, the answer to research question 2 is that bridge inspection professionals underscored the importance of clear, concise, and easily implementable research findings. A recurring sentiment among participants was the challenge of understanding and implementing certain research products, especially when they appear too theoretical or overly complex. For these professionals, often pressed for time, sifting through lengthy journal articles is not always feasible. Therefore, research needs to be straightforward and directly applicable to a variety of bridge types and conditions. There is a clear call for collaboration between researchers and practitioners. The consensus among 70% of the participants was that joint efforts can yield better, more applicable results, ensuring that academic endeavors align with on-ground needs. Additionally, practitioners emphasized the value of having summary insights from research studies. Such summaries, potentially shared through platforms where researchers and professionals interact, could save valuable time and ensure that critical knowledge is disseminated efficiently. Conferences, like TRB, were highlighted as pivotal forums for this exchange. Furthermore, to ensure the practicability of research findings, bridge inspection researchers could consider leveraging methodologies like technology readiness scales or the product evaluation criteria by NCHRP. Such structured assessments can guide both researchers and DOTs to determine a research product's maturity and its feasibility for large-scale deployment.

4.3. Research Question 3: Organizational Change in DOTs

Themes 4 and 5: Change Barriers and Facilitators

Members of the bridge inspection divisions provided valuable information about factors that can contribute to successful organizational change in DOTs. Some of these factors correspond to elements found in well-established organizational change models and implementation theories. First, showing the need for change was mentioned by participants as a necessary step to implement a new idea in the bridge inspection divisions: "*Our bridge engineer is very willing and not afraid of change, but he wants to know that whatever change or idea it is, that it's going to be a benefit to us. We are not doing something because it is just the thing to do*" (L2 employee). Ref. [39] indicates that the first step toward a successful change process is to establish a need or urgency to change. Leaders need to explain to staff members the benefits of change to create a sense of readiness among staff members and avoid staff resistance [44]. Similarly, an L2 participant found that explaining to bridge inspectors why they need to apply this new technology or process improves their quality of work. Convincing staff members with the urgency of change requires creating a vision or a list of objectives they can relate to. This can help identify the barriers to change and create a strategy to reach the required outcomes [39].

Based on several case studies in US local governments, [77] found that the need for change does not have to come from top managers or leaders but can emerge from problems workers are experiencing and managers might not be aware of. In the bridge inspection divisions, bridge inspectors (Level 3) should take the initiative and present to program managers their problems during inspections and try to figure out actions that can help improve the inspection process. Moreover, if researchers have a strong understanding of the DOT needs, researchers can play the role of change leaders and try to persuade state DOTs and the FHWA with a new research idea that can solve their problems or lower their costs. In fact, some DOTs try to encourage researchers by providing them with new research ideas. For example, Colorado DOT (CDOT) has an applied research and innovation program that encourages researchers to present research ideas as problem statements, and if the project gets selected, a funding contract will be provided to the researcher or the university as primary investigators [78]. However, CDOT requires researchers to select or work with one of its staff members as a project/research "champion" who will be responsible for implementing research recommendations [78].

Changes in DOTs' bridge inspection practices and policies require the support of the FHWA. The organizational change literature related to public organizations contains evidence that change leaders need to justify to external stakeholders the need for change, especially if these stakeholders have the ability to provide the necessary resources and should authorize the change before it even starts [79]. However, participants mentioned that one of the main barriers to change is convincing the FHWA of the importance of this change and its benefits: "*Convincing management and the FHWA that organizational changes were necessary was probably the biggest barrier*" (L1 employee). On the other hand, the FHWA can help stimulate change and promote urgency among DOTs by mandating changes that they see as necessary or showing dissatisfaction towards a DOT's performance that requires immediate change. One of the DOTs involved in this study initiated change and developed a centralized inspection team to improve inspection data after being warned by the FHWA. Ref. [80] found that mandating policies or new standards in public organizations can speed change and create a feeling of urgency among staff members.

The role of the FHWA during change and implementing new technologies in bridge inspection programs was an overarching topic mentioned by several participants on different occasions. Gaining support from the FHWA can help push the change forward and institutionalize change among DOTs. The study found that the FHWA can support DOTs during change by: (1) providing guidance and administrative and technical help during change, (2) giving DOTs time to implement change, and not quickly overburdening them with regulations and requirements that cannot be reached at early stages of the implementation process, (3) ensuring that change goals are clear to remove ambiguity and differences among DOTs, (4) acknowledging that each state has different types of bridges, resources, climates, and demographics, and accordingly, regulations need to be flexible and allow room for adjusting the new procedures to fit the DOTs capabilities, (5) helping DOTs find the required financial resources during change, and (6) developing policies that offer standard and applicable frameworks for research transfer in transportation agencies.

Focusing on staff members and preparing them for the change can also play an important role in achieving a successful transition [44]. Level 1 and 2 participants found that one of the main reasons that led to a successful change in their department was the commitment and quality of the staff members: "*I think what made the transition successful is dedication and persistence of our staff, wanting to realize the changes necessary to make our program a success*" (L1 employee). As a part of creating readiness for change, [44] stated that leaders need to motivate staff members, communicate with them, and show them the change goals and that they have the ability to succeed and participate in this change. Communication between leaders and staff members during change can help reduce uncertainty and ambiguity during change [44], which was a problem some participants experienced during organizational changes: "*The challenges personnel faced, was to understand what is the job responsibility, what is the hierarchy list, who to contact, and who I have to call for a question if there is a maintenance question, or if there is a critical finding. I think there was a lot of uncertainty throughout the state*" (L3 employee). Also, it is essential that leaders present to staff members the short and long-term goals of this change process to create a clear vision of the outcomes of this change, monitor progress, and create a sense of direction among staff members [39].

Participants also mentioned that applying a new inspection planning framework or adapting new tools during inspections will require skilled staff members trained on the new procedures. Most participants agreed that training is the most important factor to improve inspection quality and facilitate change. Researchers have found that training can provide staff members with the knowledge they need to implement with confidence a new technology, and even measure its applicability [18]. Training can help staff members see change as an opportunity for growth and advancement in their careers, especially if they are rewarded with promotions or certificates after attending the training [81].

Managing the workforce and having enough skilled workers to conduct the change was mentioned among participants as an important factor that can influence the change process and should be considered before deploying any change. Ref. [21], agreed with our findings and commented that in transportation agencies limited skilled personnel can be a hurdle to transfer research findings into practice. Having an understaffed organization will increase stress and the risk of falling behind during change since staff members will not have enough time to simultaneously work on their primary responsibilities and cope with the new procedures [82]. In some cases, transportation agencies can reach out to external expertise and even hire part-time workers to carry on with the primary duties of the organization until the in-house staff members adapt to the new change process. Moreover, two participants mentioned that one of the main problems in applying a variable inspection planning framework is managing bridge inspectors since a variable inspection schedule will lead to downsizing or hiring new inspectors, which is not an easy task in public organizations. Therefore, researchers in the field of bridge inspection planning need to provide DOTs with frameworks or models that can help them efficiently manage their resources and predict the number of inspectors they will need to implement a new inspection program.

All of the above factors can help accelerate change, however, limited resources or insufficient funding can lead to feeble implementation or change efforts. Indeed, implementing a new research idea can help save resources and time, but change is not cheap and requires ample resources to reach the desired outcomes [40]. Several participants mentioned that one of the main barriers to implementing a new idea is the limited budgets most DOTs currently have: "*I think ours and most DOTs, our budget is really limited making big changes difficult for us right now especially if it will cost a lot of money unless it has a big benefit to it*" (L2 employee). Ref. [83] found that sufficient funding is one of the important factors in improving public organizations and promoting innovation. Funding during change will be required to train and prepare staff, purchase the required equipment, promote and communicate new ideas among practitioners in the field, and restructure the organization [84]. Ref. [21] acknowledges that most innovation promoters in the transportation sector depend on ad hoc approaches for gaining funds, which is an unreliable process and has proven to only provide incremental changes. Therefore, transportation organizations need to establish sustainable funding sources that can support innovation in these organizations.

One common factor was found among all the change-driving aspects mentioned by participants, which is having a strong leadership able to communicate the need for change, gain support from the FHWA, prepare staff members and motivate them, manage the workforce, and find sufficient resources: "*What made the transition happen honestly is that somebody made a decision, they wanted to go in that direction, and they went, and it was amazing*" (L3 employee). The literature is full of evidence on the importance of leadership and top management support during change [39,79,84–87]. Change leaders can be a single individual [86], or a group of staff members able to guide the change process [39,85]. Change in bridge inspection programs will require leaders able to control change, identify and mitigate barriers, and form a coalition among DOT staff members and the FHWA to accelerate the change process from all directions.

Finally, some staff members in the bridge inspection divisions might find these propositions as common sense, however, studies have found that managers sometimes ignore or underestimate some of these factors [40]. Also, our focus was mainly on bridge inspections and DOT departments, however, one can infer that these factors can help other transportation agencies and government organizations in applying change and implementing new research findings.

To answer research question 3, in summary, bridge inspection divisions highlighted the importance of clearly showing the necessity for change. Ensuring that any new implementation is practical and well-understood by staff is paramount. Leaders must articulate the benefits and goals of the change to create a sense of readiness and reduce resistance. This may be further facilitated by staff members, including bridge inspectors, who actively voice the issues they face and propose innovative solutions. Gaining support from the FHWA is crucial, as it can either be a catalyst or a barrier to change. Effective communication strategies should be employed to alleviate uncertainties during transitions. Training is vital, ensuring that staff members are equipped with the necessary knowledge and skills to embrace new technologies or processes. Managing the workforce and ensuring there is a sufficient number of skilled workers, is essential, as is securing adequate funding to support the implementation phase. Leadership plays a pivotal role in guiding the process, securing support from higher authorities, and rallying staff behind the vision. While these findings are central to bridge inspection practices, they offer valuable insights for broader DOT departments and other public sectors aiming to implement research-driven changes.

5. Conclusions and Future Research

The purpose of this study was to identify the factors that can help improve research products and accelerate change and research transfer in bridge inspection departments. This study used semi-structured interviews, written interviews, and questionnaires for data collection to provide rich and accurate results. During the analysis of current inspection practices, it was found that many researchers in the field of bridge inspection planning do not support the 24-month inspection cycle used to schedule routine inspections. However, during our discussion with DOT staff members, it was found that most participants support the 24-month inspection cycle since it is a simple and safe scheduling approach. Also, during our analysis of current inspection methods, participants indicated that the barriers to implementing NDE techniques are the training required by inspectors, traffic control, and the required access equipment. Furthermore, the study found that in order to improve research products in the bridge inspection field, researchers need to collaborate with practitioners and provide practical research results that can be applied to different bridge cases. During innovation and transition, change leaders need to focus on preparing staff members, showing the benefits of change, and gaining support from the FHWA. In addition, DOTs and leaders need to support the change process and provide the necessary resources required to implement a new technology or framework. Finally, future research should focus on including other stakeholders such as FHWA staff members, staff members from the research and development department, and consultants working in bridge inspections. This study focused on DOTs in the U.S., however including transportation agencies from other countries will provide a broader picture and can even yield different results.

While this study offers significant insights through its qualitative approach, certain inherent limitations must be acknowledged. One of the primary concerns revolves around the participant selection and response rate. Despite the use of maximum variation sampling aiming to encapsulate diverse perspectives, the achieved 35% response rate may not adequately represent the broader community within DOTs. This selection could lead to potential biases, limiting the study's generalizability. Moreover, the job descriptions used were generalized, and while these broad roles were designed to capture a wide range of responsibilities across different DOTs, the actual nuances in roles and responsibilities across states could have led to variations in insights, possibly affecting the study's conclusions.

The methodological approach, predominantly qualitative, also presents limitations. Thematic analysis, while insightful, is prone to researcher biases during inductive coding. Even with rigorous measures such as the involvement of all authors in iterative discussions and triangulation, the risk of shared biases, groupthink, or confirmation bias stemming from the interplay of inductive and deductive coding cannot be entirely negated. Furthermore, the non-recording of certain interviews, at the request of participants, introduces potential inaccuracies due to reliance on memory, despite the mitigative measure of member checks.

The member check process itself is not foolproof, given the dependence on participants' recall abilities and potential shifts in their perspectives over time. Such challenges inherent in subjective interpretation and data collection nuances might have influenced the depth and accuracy of the findings.

In reflecting upon this research journey, feedback from the bridge inspection community underscores the value of more extensive, statistically driven studies in the future. The present research encompasses insights from 26 participants spanning various states in the US, casting light on the intricacies of innovation and research transfer within bridge inspection. The intent behind this study is chiefly exploratory. Percentages presented within findings, though qualitative in nature, aim to elucidate dominant trends and prevailing sentiments. The forward path reveals a potential and recognized need for an encompassing study that taps into the wider community of bridge inspectors across DOTs. Such pursuits would further strengthen the research groundwork in this specialized domain and corroborate the pioneering insights this study brings forth.

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Appendix A. Bridge Inspection Questionnaire

1. How do you schedule a routine bridge inspection? Do you follow a fixed interval (e.g., 2 years) or do you use other methods?
2. What techniques do you use for routine bridge inspection? (E.g., visual inspection-nondestructive testing (NDT) methods).
3. From your experience, what actions can be performed to improve routine bridge inspections?
4. Based on the data collected during routine inspection, what decisions can be made? (E.g., repair needs to be completed immediately, in-depth inspection is required. . ., etc.).
5. How do you estimate the average cost of a routine bridge inspection? And what are the cost items you consider during your estimation (e.g., inspectors' hourly wage, rent of snooper. . ., etc.)?
6. What rating system do you follow to evaluate the condition of a bridge? (E.g., NBIS rating system or AASHTO element level ratings). And do you use any software to help in the management process (e.g., AASHTOWare or BRIDGIT)?

Appendix B. Journal Articles Interview

1. Are there any questions regarding the explained inspection program that you would like to ask before we start our questions?
2. How hard do you find this inspection program to understand? Hard, medium, or easy, and why?

3. Does your agency currently have the data and resources needed to implement this program?
4. If you were not constrained by federal law, would you be interested in implementing this inspection program? And why? Or why not?
5. If the answer is yes, then how long would it take you for this transition? What tools, software, and training will be required to implement this program?
6. Will you still need to have different inspection protocols (routine inspection or in-depth inspection), or can this inspection program be conducted on its own?
7. Can this inspection program be applied to a bridge network? And if yes what will be the data required for this implementation process?

(Note: Questions 8 and 9 will be asked one time only and not repeated for every article):

8. How often do you use nondestructive testing (NDT) methods in bridge inspection?
    (a) Are there any barriers to implementing NDT and using them in routine inspections?
    (b) How do you rank the quality of an NDT method? Do you use the probability of detection (i.e., like the articles discussed earlier)? Or do you only use standard error and accuracy?
    (c) Does your bridge inspection manual consider NDT?
9. How likely can the recommended interval between bridge inspections (2 years) be changed or extended?
    (a) Do you think the 2-year inspection interval is efficient and cost-effective?
    (b) From your experience, how can routine bridge inspections be scheduled?

Appendix C. Organizational Change Interviews

1. In your department, have you witnessed any organizational changes or implementation of new practices?
    (a) Why did your department initiate the transition?
    (b) How did employees feel about this transition? Did they agree to this change?
    (c) If the transition was successful, what were some factors that made the change successful?
    (d) If it was not successful, what were the barriers?

2 Do you think implementing a new bridge inspection program is necessary in your department?

   (a) From an organizational standpoint, what changes will be required to implement a new inspection program?
   (b) What will be the desired outcomes from this change?
   (c) What is the current organizational hierarchy? And will it be affected by the new inspection program?
   (d) Are benefits from this change enough to motivate leaders and employees to get engaged in the change initiatives?
   (e) From your experience, what other incentives can be provided to professionals to encourage the implementation of new technologies and research findings in your organization?
   (f) Can setting short-term goals help in creating a sense of achievement and guidance for this change?
   (g) What would those short-term goals be?
   (h) From an organizational perspective, what challenges will emerge in order to utilize new inspection programs and implement them in state governments?
   (i) Which stakeholders should be involved in planning and executing this transition?
   (j) What can academics and researchers do to help bridge managers and inspectors implement new research findings and reduce the gap between academia and the industry?

Appendix D. Written Interviews

(Q1) Do you think the 24-month inspection cycle currently used to schedule routine inspections for most bridges is efficient?

Yes.

No.

In some ways yes, in some ways no.

If yes or in some ways yes, in some ways no: (Q2) What are the main advantages of the 24-month inspection cycle? Please list a few brief ideas.

If no or in some ways yes, in some ways no: (Q3) What are the main drawbacks of the 24-month inspection cycle? Please list a few brief ideas.

Research in the field of bridge inspection planning has been conducted extensively, and different approaches for scheduling bridge inspections have been proposed. For example, the National Cooperative Highway Research Board (NCHRP) has presented a risk-based approach for determining the bridge inspection interval in the NCHRP Report 782 based on the NCHRP 12-82 study. In this approach, the DOT would need to establish a risk assessment panel consisting of experienced bridge engineers in the field of bridge inspection. The panel would identify the expected damage modes and attributes for the main bridge components and determine the probability and consequence of failure of each bridge component. Based on the risks associated with the bridge component, an inspection interval would be determined as 12, 24, 48, 72, and 96 months and can be changed depending on the DOT requirements. The component with the shortest inspection interval would be the controlling component and its inspection interval would be used for the whole bridge. The Federal Highway Administration (FHWA) has also been considering a similar approach as an alternative for scheduling bridge inspections.

(Q4) Would your department consider applying new bridge inspection scheduling approaches like the one described above?

Yes, we would, right away.

Maybe, we would wait to see the experiences of other states in applying new approaches before making a decision.

No, we would not.

If yes or maybe: (Q5) What additional information and resources would be needed by your department to switch to a new bridge inspection planning approach like the one described above? Please list a few brief ideas.

If yes or no or maybe: (Q6) What obstacles do you see in trying to implement a new inspection planning approach like the one described above? Please list a few brief ideas.

Applying a new inspection plan may involve some organizational changes such as changing the department's organizational team structure, hiring new personnel, or altering underlying procedures and technologies used in daily operations.

(Q7) Will switching to another inspection planning approach require organizational changes in your department?

Yes.

No.

Maybe.

If yes or maybe, please answer question 8; if not, move to question 9.

(Q8) What organizational changes do you expect might be required? Please list a few brief ideas.

(Q9) From your experience, what incentives can be provided to professionals to encourage the implementation of new technologies and research findings in your organization? Please select all that apply.

(a) Show them the benefits of this change.
(b) Provide appropriate training.
(c) Get them involved in the planning phase of the change.
(d) Other. . . . .

(Q10) From an organizational perspective, what challenges will emerge in order to implement new inspection techniques and planning methods in state governments? Please select all that apply.

(a) Money and other resources.
(b) Human resistance to change.
(c) Other . . ..

(Q11) What rating system do you follow to evaluate the condition of a bridge?

(a) NBI rating system.
(b) AASHTO element level.
(c) Both systems.
(d) Other. . .. .

(Q12) What software do you use to manage inspection data?

(a) AASHTOWare
(b) BRIDGIT
(c) Other . . ..

(Q13) Approximately how many total bridges are in your state?

(Q14) Of these bridges, approximately how many is your state DOT responsible for inspecting and maintaining?

(Q15) Do you think that the quality of the information gathered during bridge inspections and resulting inspection reports are sufficient?

Yes.

No.

If no, (Q16): Please list the issues you identify in the quality of the information gathered during bridge inspections and resulting inspection reports. Any suggestions to address those issues?

(Q17) What can academics and researchers do to help bridge managers and inspectors implement new research findings and reduce the gap between academia and industry? Please list a few brief ideas.

Finally, we would like to thank you for your participation and the valuable information you provided. If you have any comments/feedback or any other advice on how to improve bridge inspections you would like to add, please add those comments below.

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