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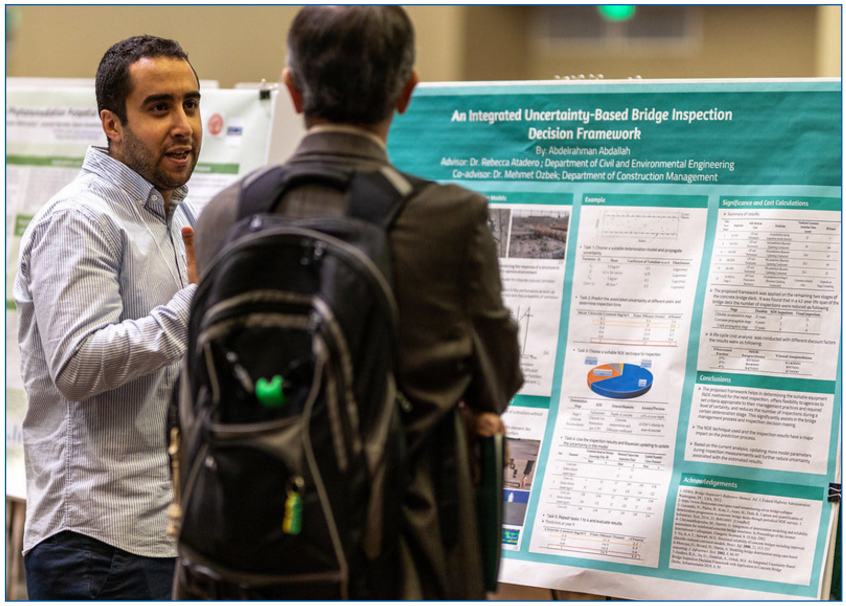
TRANSFERRING RESEARCH INNOVATIONS IN BRIDGE INSPECTION PLANNING TO BRIDGE INSPECTION PRACTICE



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16. Abstract

Over the last two decades many researchers have focused on providing new ideas and frameworks that can help improve conventional bridge inspection practices; however, little guidance is provided for implementing these new ideas in practice. This, along with resistance to change and complexity of the proposed ideas, resulted in a lack of success in applying new technologies in bridge inspection programs. Accordingly, this qualitative study aims to identify the factors that can help improve research products and accelerate research transfer in bridge inspection departments. This study used semi-structured interviews, written interviews, and questionnaires for data collection to provide rich results. From among different departments of transportation (DOTs), 26 bridge personnel were involved in this study. Although the study focuses on the field of bridge inspection, the findings of this study are expected to have some generalizability to other significant changes to engineering practice at DOTs. Participants stated that collaboration between practitioners and researchers can help improve research products. Also, to facilitate change in transportation organizations, participants suggested that change leaders should focus on showing the need for change, gaining support from the FHWA, allocating the required resources, and enhancing the capacity of DOT staff members through training and effective communication.

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ABSTRACT

Over the last two decades many researchers have focused on providing new ideas and frameworks that can help improve conventional bridge inspection practices; however, little guidance is provided for implementing these new ideas in practice. This, along with resistance to change and complexity of the proposed ideas, resulted in a lack of success in applying new technologies in bridge inspection programs. Accordingly, this qualitative study aims to identify the factors that can help improve research products and accelerate research transfer in bridge inspection departments. This study used semi-structured interviews, written interviews, and questionnaires for data collection to provide rich results. From among different departments of transportation (DOTs), 26 bridge personnel were involved in this study. Although the study focuses on the field of bridge inspection, the findings of this study are expected to have some generalizability to other significant changes to engineering practice at DOTs. Participants stated that collaboration between practitioners and researchers can help improve research products. Also, to facilitate change in transportation organizations, participants suggested that change leaders should focus on showing the need for change, gaining support from the FHWA, allocating the required resources, and enhancing the capacity of DOT staff members through training and effective communication.

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1. INTRODUCTION

The viability of our nation's infrastructure depends on continuous innovation and organizational cultures that encourage the application of valuable research ideas and technologies (Hood et al., 2014). In the transportation sector, several strategies have been employed to accelerate research transfer into practice; yet these approaches did not provide the desired outcomes, and a lag between academia and the industry persists (Dekelbab, Hedges, & Sundstrom, 2017; Harder, 2014). In this qualitative study, we focus on the field of bridge inspection planning and the reasons behind the gap between researchers and practitioners in the industry. While our study is within the specific context of bridge inspections, we seek to provide insights about how to facilitate research implementation and change in state departments of transportation (DOTs) that can be generalized and applied to other aspects of transportation or government organizations.

Bridge inspection planning is a non-trivial process impacted by various uncertainties and contradicting objectives (Morcous, Lounis, & Cho, 2010). Accurate and timely bridge evaluations can help maintain a safe and reliable bridge network while optimizing the cost of repair activities, reducing the overall expenditure on bridges (Kim, Frangopol, & Soliman, 2013). In the United States, routine bridge inspections are conducted every 24 months regardless of the bridge condition and using visual inspection, which has been reported to be subjective, uncertain, and limited to detecting deteriorations that have emerged on the structure's surface (Graybeal et al., 2002). The limitations of current inspection practices have been documented in several studies, and a variety of improvements, such as changes to inspection intervals, have been the focus of several researchers (Parr, Connor, & Bowman, 2010; Soliman, Frangopol, & Kim, 2013; Washer, Connor, Nasrollahi, & Provines, 2016a), implementing nondestructive evaluation methods (Gucunski et al., 2015) and drones (Hubbard & Hubbard, 2020; Seo, Wacker, & Duque, 2018), and developing new software and database management systems that can enhance the inspection management process (Abdelkhalek & Zayed, 2020).

However, despite these research efforts and their potential to improve inspection quality and save inspection time and resources (Clarke-Sather, McConnell, & Masoud, 2021), DOTs and the Federal Highway Administration (FHWA) have not yet adopted significant changes and still depend on conventional inspection methods, which cost around $1.3 billion dollars each year (Zulifqar, Cabieses, Mikhail, & Khan, 2014). Therefore, the qualitative study presented herein aims to engage with transportation agencies to conduct a descriptive and practical analysis of the barriers limiting the transfer of new ideas and technologies into DOTs and the actions that can be conducted to improve research products. Data analysis was conducted using a thematic framework, and research findings are presented accordingly.

2. PURPOSE

The benefits of research results begin after practitioners and organizations use them in practice (Dekelbab et al., 2017). However, there is no ultimate solution or action plan to facilitate the implementation of research in practice as each type of action and implementing agency is unique; it is more of a combination of recommended protocols and frameworks (Harder, 2014). Implementing research requires a team of skilled and experienced people in the field of implementation. The knowledge and expertise for accomplishing the necessary activities associated with implementing a new research product is important for a smooth transition process, whether the expertise lies in the party presenting the research idea or the other party implementing the idea into practice (Hood et al., 2014). In addition, there are several factors that can affect the research transfer process, such as the quality of the research products, organizational culture, time constraints, limited resources, and government policies and procedures (Fixsen et al., 2005). To help the transportation community develop a research implementation infrastructure and facilitate research transfer in DOTs, the objectives of this study are:

1. Analyzing the current situation in bridge inspection practices by engaging with different DOT staff members and investigating their opinion on some of the approaches they use in current inspection practices such as the 24-month inspection cycle used in routine inspections, NDE methods, and visual inspections.
2. Identifying the factors that can help improve research efforts in the field of bridge inspection to provide the transportation community with usable and implementable research products.
3. Making a strong connection between research implementation and organizational change, hence another important objective of this qualitative study is to identify the barriers to adoption of new inspection techniques and planning methods from an organizational culture and change perspective.

Although the study focuses on the field of bridge inspection, the findings of this study are expected to be both specific to changes in bridge inspection practices and have some generalizability to other significant changes to engineering practices at transportation agencies.

3. LITERATURE REVIEW

In this literature review, we focused on three major topics: bridge inspection, research transfer, and organizational change. These topics are very broad; however, to achieve our study objectives we focused on the aspects that are directly related to the framework of our study and can help us develop our data collection methods (described subsequently).

First, we overviewed some of the main features of bridge inspections, which is the context of our study. We aimed to understand current inspection standards, especially the aspects related to routine inspection planning, inspection methods, and data management. This body of literature identifies the limitations associated with current practices and the main areas of research focus. This background was essential to analyze the current situation in DOTs and develop interview questions to collect required information on current practices. Also, reviewing the research efforts in bridge inspection planning helped us identify the research products that were used during our interviews on how to enhance research products in the bridge inspection field.

Strategies to improve research transfer are evident in the literature in different scientific fields (Fixsen et al., 2005). Thus, in the research transfer topic we tried to review the problems researchers, sponsors, and practitioners in different domains face while implementing new research findings. We then aimed to identify the strategies that can help overcome these challenges and be applied in the transportation sector.

Implementing new research products requires organizational change and development in DOTs' culture (Harder, 2014). In the third section of the literature review, we focused on the factors and models that can help facilitate organizational change and avoid resistance (Al-Haddad & Kotnour, 2015). We used this information to accomplish our third study objective and discuss with participants their experience with organizational change and if they agree that the change drivers found in the literature can help facilitate change in DOTs or not. Moreover, participants in this study are not experts in change theory and models so we needed the required information as investigators to develop a well-structured and informative discussion (Alshenqeeti, 2014). The information on organizational change also allowed us to identify the stakeholders that we need to contact for a rich and diverse perspective.

3.1 Bridge Inspection

There are different types of bridge inspections in the United States: initial, routine, in-depth, damage, fracture critical, underwater, and special inspection (AASHTO, 2011). Routine bridge inspection is the most common type of inspection and, based on the requirements of the FHWA and the National Bridge Inspection Standards (NBIS), routine inspection is usually conducted every two years using visual evaluation. The information gathered during inspections helps in reporting bridge conditions using the National Bridge Inventory (NBI) rating system (FHWA, 1995) or the AASHTO element level rating system (AASHTO, 2013; Farrar & Newton, 2014). Inspection reports are then incorporated into the state Bridge Management System (BMS) and NBI database (Farrar & Newton, 2014).

However, current bridge inspection programs have been associated with several uncertainties and limitations that have been addressed in previous research (Atadero, Jia, Abdallah, & Ozbek, 2019; Graybeal et al., 2001; Nasrollahi & Washer, 2015; Parr et al., 2010; Phares et al., 2004). During routine inspection, inspectors are exposed to risks of injury due to limited accessibility and mobility in some locations (Hallermann & Morgenthal, 2014). Inspectors' qualifications and training may significantly vary, which can affect the quality of the reported inspection data (Ahamdi, 2017). Further, general and subjective visual inspections are limited to surface defects and associated with a high level of uncertainty (Kim, Gucunski, & Dinh, 2019; Morcous et al., 2010). Another major concern about current bridge inspection programs is that there is no engineering justification for the 24-month inspection cycle specified for routine inspections (Washer et al., 2016a). The calendar-based inspection interval does not consider the condition of the bridge or the in-service environment. In fact, some studies have concluded that this approach is not the most cost-effective method for scheduling bridge inspections, and can waste resources and lead to unnecessary or delayed inspections and risks (Atadero et al., 2019; Nasrollahi & Washer, 2015; Soliman & Frangopol, 2014; Washer et al., 2016a).

Due to the limitations of visual inspections, some researchers have focused their effort on developing and accessing nondestructive evaluation (NDE) techniques (Gucunski et al., 2013; Gucunski, Maher, Ghasemi, & Ibrahim, 2012; Yehia, Abudayyeh, Nabulsi, & Abdelqader, 2007), integrated systems (Gucunski et al., 2015; La, Gucunski, Dana, & Kee, 2017; Lim, La, Shan, & Sheng, 2011; Vaghefi, Ahlborn, Harris, & Brooks, 2015), and automated unmanned inspection methods (Hallermann & Morgenthal, 2014; Hubbard & Hubbard, 2020; Seo et al., 2018; Wells & Lovelace, 2018; Xu & Turkan, 2019). These techniques mainly depend on the bridge construction material and the defect that needs to be analyzed (Alampalli & Jalinoos, 2009; NCHRP, 2006; Ryan, Mann, Chill, & Ott, 2012; Vaghefi et al., 2012).

In addition, to establish a more systematic approach for inspection scheduling and planning, various frameworks with different approaches, such as reliability-based inspection methods, risk-based inspection methods, and optimization-based inspection frameworks, were proposed (Abdallah, Atadero, & Ozbek, 2021). Reliability-based methods help in conducting inspections before failure, while considering the uncertainty in the bridge capacity and applied loads (Dong & Frangopol, 2015; Kwon & Frangopol, 2011; Orcesi & Frangopol, 2011; Soliman & Frangopol, 2013; Straub, 2014; Straub & Faber, 2002). Risk-based inspections consider the probability and consequences of a structure failure, and some of these studies quantify risk using mathematical approaches (Faber, 2002; Haladuick & Dann, 2018; Liu & Frangopol, 2019; Yang & Frangopol, 2018a), while others use expert judgment (Nasrollahi & Washer, 2015; Parr et al., 2010; Washer et al., 2016a). Optimization approaches help in finding the optimum inspection time and method while considering a single objective or multiple objectives and providing a range of Pareto front solutions the bridge inspection planner can choose from (Chung, Manuel, & Frank, 2006; Kim & Frangopol, 2011, 2017, 2018; Kim, Frangopol, & Zhu, 2011; Kim, Ge, & Frangopol, 2019; Soliman & Frangopol, 2014; Soliman et al., 2013; Soliman, Frangopol, & Mondoro, 2016).

In our study, we focused on discussing with participants their opinions on the 24 months used to schedule routine inspections and the alternative approaches presented in the literature. We also discussed the problems practitioners face when using new technologies during inspections, such as NDE methods. Inspection scheduling frameworks and NDE methods were our main examples of research products that were used to generate a discussion with participants on the problems they find with research products in the bridge inspection field.

3.2 Research Transfer

Research transfer or implementation can be defined as a set of actions with defined dimensions designed or initiated to put valuable and applicable research findings and technologies into practice (Fixsen et al., 2005). Accelerating research implementation has been the aim of several organizations; however, research conducted to define a set of successful approaches or models has been limited (Harder, 2014). The U.S. Department of Defense has found that depending on more than one strategy during research implementation will lead to better results than depending on a single approach (Csoma, 2010). However, research implementation strategies are not cheap and require resources and enough time to provide training and technical expertise, conduct marketing campaigns to explain the merits of the new technology, and compensate for the delay in performance that can happen until all staff members are comfortable with the new technology (Klein & Knight, 2005). In the public sector, Cáñez, Puig, Quintero, and Garfias (2007) claim that one of the main barriers for research implementation is the rigorous and bureaucratic process required to attain the required resources to support innovation implementation, which requires significant effort and time. Accordingly, Grol and Jones (2000) found that in order to accelerate research implementation and allocate the required resources, organizations need to develop a research implementation infrastructure with systematic implementation frameworks and clear policies.

In the United States, some key organizations promote research and technology transfer. 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 entire field (Dekelbab et al., 2017). The NCHRP is focusing on providing effective research products and implementation frameworks and enabling implementation cultures in transportation organizations (Harder & Benke, 2005). Several key players have been involved in those studies, including the Transportation Research Board (TRB), American Association of State Highway and Transportation Officials (AASHTO), state DOTs, and the FHWA (Dekelbab et al., 2017). Some of the research efforts have been presented in transportation conferences and guides published by the NCHRP (Burke, 1984; Harder, 2014; Harder & Benke, 2005; Hood et al., 2014; Steven et al., 2013). Also, the Strategic Highway Research Program 2 (SHRP 2) has been one of the national examples in commitment to funding and providing expertise for research implementation. The SHRP 2 has allocated a $75 million budget to help support research transfer in the highway sector (Steudle, 2012). On 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) Act (Harder, 2014). Additionally, a few DOTs, such as in Pennsylvania, have developed a state council 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 (Bonini et al., 2011).

The National Implementation Research Network (NIRN) is another example of the effort done in the field of research implementation and the resources that can help facilitate research transfer (Metz, 2015). NIRN focuses on conducting technology transfer and implementation research, provides updated reviews on new frameworks and approaches in the research implementation field, and communicates with governments and research domains to help implement evidence-based practices (Harder, 2014). In 2005, NIRN provided a systematic framework for research implementation that can be applied in different scientific fields (Fixsen et al., 2005). The model consists of the following steps: 1) exploring the problem that needs to be solved and deciding on implementing a research finding to solve this problem, 2) identifying the resources needed for implementation, 3) launching an initial implementation process to identify barriers, 4) fully operating the new technology and making sure that staff members are successful in applying the new process, 5) evaluating the new practices and learning from feedback, and 6) ensuring that the new practice will be sustainable and survive for a long term (Fixsen et al., 2005).

Moreover, innovation needs people with strong connections to match researchers with sponsors and business companies (Kanter, 2006). A study conducted by Mariello (2007) found that many researchers do not like getting involved in marketing or commercialization aspects to promote their research ideas. Thus, researchers in some cases need to be teamed up with business partners able to convince potential clients to adapt the new technology (Mariello, 2007). In this context, the Manufacturing Extension Partnership (MEP) is a program managed by the federal government and the National Institute of Standards and Technology (NIST) that helps researchers in the manufacturing industry commercialize and market their ideas in the industry (Schacht, 2011). MEP helps labs seeking to transfer their new ideas connect with the manufacturing industry. The program also provides technical expertise and training for manufacturers willing to apply a new technology to reduce resistance among workers. The objective of this model is to facilitate research implementation in order to create new jobs, increase production and sales, and reduce manufacturing costs (Schacht, 2011). Creating a similar approach in the transportation sector or in the bridge inspection field can help in promoting and commercializing relevant innovations in the field, such as NDE methods or new bridge management systems. It can also help in involving the public organizations in the research process by providing researchers with test locations and opportunities to demonstrate their research findings (Harder, 2014).

In addition, the federal government is continuously developing new partnerships with private intermediaries to help implement scientific findings coming out of federal labs into practice (Harder, 2014). This strategy has been used by many government organizations to allocate solutions for some of their problems through university and individual research efforts (Bauer & Flagg, 2010). The primary goal of the private intermediaries is to market new research findings and provide organizations with agile research implementation frameworks. These organizations can help small innovators in obtaining the necessary funding for their research and legalizing research findings to accelerate its implementation (Bauer & Flagg, 2010). A similar model is the Entrepreneur in Residence (EIR) program implemented by the University of California Los Angeles (UCLA), which helps students and faculty members in the university build a business strategy, commercialize their research ideas, and reach venture capital firms (Harder, 2014).

Also, to enhance collaboration between practitioners in the field of research implementation, the Global Implementation Conference (GIC) is a biannual meeting held for researchers and practitioners from different countries and domains to address and discuss different topics about research implementation and technology transfer (GIC, 2011). The conference focusses on presenting new ideas and successful practices about implementation science and creating practice groups and workshops to educate participants (GIC, 2011). Fitting another conference in the schedule of DOT staff members or researchers in the transportation sector might be challenging. However, organizing similar conferences or workshops that focus on research implementation or technology transfer in the transportation sector might result in more innovative cultures in the transportation community and reduce the gaps between researchers and practitioners (Hood et al., 2014).

One of the main barriers of research implementation in the transportation community is depending on a single individual or champions to lead change and not have a systematic implementation process managed by a qualified team of implementation experts (Dekelbab et al., 2017). Currently, some organizations such as the Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA) are using research transition teams responsible for implementing new research ideas and mitigating barriers during the transition process (Coppenbarger et al., 2012). Research transition teams consist of a skilled staff that has sufficient knowledge of science implementation frameworks and credible connections with different academic organizations, government officials, funding resources, and sponsors (Levi & Slem, 1995). Using research and development teams helped the FAA and NASA in accelerating innovation implementation in their organizations and establishing a sustainable model for research transfer (Johnson & Barmore, 2016).

Mahoney (2009) reported that training organizational staff on implementing new research findings for solving small and specific problems can help reduce the lag between research and practice. This initiative will remove the fear some humans experience before accepting a new idea in practice and accelerate research implementation (Mahoney, 2009). Rogers (2010) found that training alone will not lead to sufficient changes in research implementation but can help reduce resistance to change among the workforce and make staff members feel prepared for the new technology. The Federal Laboratory Consortium for Technology Transfer (FLC) focuses on providing training for different stakeholders in the research transfer process. FLC trains researchers on how to build an implementation plan for their research ideas; it provides government officials and managers from different entities with tools that can help them evaluate research ideas and identify best implementation practices (Bauer & Flagg, 2010). Wandersman et al. (2008) stated that training staff members on different approaches to research implementation can improve organizations’ capacity to implement new ideas.

Rogers (2010) in his diffusion theory claims that research implementation in organizations requires leaders able to motivate employees and make necessary decisions. Klein, Conn, and Sorra (2001) stated that research implementation requires an organizational culture with strong managers able to cultivate and reward innovation and provide communication and shared perceptions among all stakeholders. However, managers who control budgets and critical decisions in an industry do not have enough time to read through entire journal articles or research proposals (Barbour, 2007). Therefore, to accelerate research implementation, the Department of Agriculture developed the Joint Fire Science Program (JFSP) (Barbour, 2007). 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. Managers can easily use these synopses to analyze new scientific findings and provide critiques and feedback on the research ideas published on the program website (Barbour, 2007). This model was well received in the agriculture industry by practitioners and helped in disseminating scientific results and opening a dialogue between managers and researchers (Barbour, 2007). A similar approach can be an easy leap in the transportation sector.

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 identify the necessary steps to implement a new technology into practice and gain all the required permits (Digiantonio, Newcomb, & Matlock, 2021). The NOAA transition policy requires innovators to clearly define the purpose and outcome of the research implementation, define the data and training that will be required by the users implementing the new practice, estimate the budget that will be required to execute the project from start to end, and justify the costs of the new technology and present its benefits (Harder, 2014). The Department of Defense (DOD) has also developed the "Manager's Guide to Technology Transition in An Evolutionary Acquisition Environment," which demonstrates a clear sequential plan and activities for implementing research (Csoma, 2010). This guide helps monitor and measure progress of research implementation projects and ensures that the new technology will be according to environmental and ethical considerations. The DOD guide also provides resources and websites that can help innovators mitigate barriers of research implementation (Csoma, 2010).

One of the main reasons for technology transfer failure is deploying a new technology before reaching full maturity and applicability (Straub, 2015). Thus, NASA presented a systematic technology readiness level scale to ensure that a technology is ready for application (Laughlin, Roper, & Howell, 2007). The framework starts by observing if the new technology follows essential mathematical characteristics and formulations. Then the technology concept is formulated by providing a clear description of how the theory behind the technology serves a certain application in practice. The feasibility of the technology also must be studied while developing analytical tools to simulate the new technology. Each component of technology is then tested in a laboratory environment, followed by a test of the whole system in a prototype of the real environment to analyze the choke points in the system. The actual system is then ready for initial deployment to analyze barriers and feedback before fully launching the new technology (Laughlin et al., 2007).

Studies by Brunt, Lerner, & Nichols (2011) and Kay (2011) noted that incentives and inducement prizes can help speed technology development and accelerate research transfer into practice. Kay (2011) commented that organizations providing inducement prizes can require candidates to present a clear diffusion and implementation plan before accepting their research idea. Currently, the DOT is managing a few research challenge competitions to motivate practical research findings (Harder, 2014). Other organizations, such as the National Science Foundation (NSF), use some of the funds available as research prizes to stimulate innovation and applicable research ideas (Williams, 2012). Rumpel and Medcof (2006) state that for researchers, incentives do not have to be financial but have to motivate them about their work and the effort they are making.

There are two main components related to research implementation: the effectiveness and applicability of the research product and an organizational culture that enables innovation (Dekelbab et al., 2017). Several researchers have found that implementing a new research idea will require organizational changes that need to be well managed to reach the desired outcomes (Aslam, Muqadas, Imran, & Saboor, 2018; Heracleous & Barrett, 2001). Therefore, in the next section we present some of the main aspects related to organizational change and cultures that helped us identify the barriers that will face research implementation in the bridge inspection field from an organizational perspective.

3.3 Organizational Change

Due to rapid technological advancement, limited resources and growing global competition, change has become a norm for organizations to succeed and align their operations with changing environments (Armenakis & Harris, 2009). Many strategies have been suggested in the literature to manage change; however, organizations are different in their structure, daily operations, goals, and staff members (Appelbaum, Habashy, Malo, & Shafiq, 2012), and a one-size-fits model will usually lead to failing change (Kotter & Schlesinger, 1979). Therefore, transportation agencies need to be aware of their organizational cultures, weaknesses, and strengths before conducting an organizational change. DOTs need to also identify the scale of the change and the time it will take to implement this change. A large-scale change will be more comprehensive and lead to radical changes in the organization system, culture, and daily processes. Large changes will involve more stakeholders and require more resources than a small organizational change (Al-Haddad & Kotnour, 2015; Boyd, Lewin, & Sager, 2009). A small-scale change will lead to less disturbance in an organization, however it will result in less significant outcomes (Boga & Ensari, 2009). Also, long-term changes can be challenging and require participation of human resources in the change process to maintain a good workforce morale during the long duration of change (Harrison, 2011).

To facilitate change and transformation in an organization, it is important to identify the critical factors that will enable a successful organizational change (Chrusciel & Field, 2006). The literature provides a wide range of factors related to a successful change process. First of all, awareness of the need for change, and conducting a complete assessment of the current situation, is the beginning of any successful change process (Brisson-Banks, 2010). Hence, our first study objective is to analyze the current situation in DOTs and understand what participants think about some of the conventional approaches used in bridge inspections. Bingham and Wise (1996), stated that managers should be able to persuade employees about the urgency of change while demonstrating the benefits behind this change. Further, organizational changes that are not supported by a systematic strategy and aligned with the organization's main purpose or goal will end up failing and will not be supported by employees and managers (Smith, 2002). Kotter (1995) noted that proper planning is crucial during an organizational change to identify the environment and mindset an organization will need during a smooth transition. To reach the desired change, outcomes in the public sector, organizational change goals need to be well defined with a clear policy to avoid ambiguity and different interpretation and implementation among public leaders (Fernandez & Rainey, 2006).

Another important facet for any transition is the personnel involved in conducting and leading the change. The content and process of an organizational change needs to be aligned with the people involved and their capabilities and values (Anderson & Anderson, 2002). For example, implementing a new technology in a company without preparing the workers and training them will lead to resistance and low probability of accepting this new change (Yang & Yoo, 2004). Smith (2002) commented that the major reason behind organizational change failure is initiating a change without having enough resources and trained workforce to sustain this change. Also, implementing a new technology in an understaffed organization with limited time to learn and adapt to the new technology might be difficult due to the responsibilities and tasks required by the staff members (Desouza et al., 2009). Kanter (2006) found that allowing enough time for staff members to adapt to a new technology is important to reduce resistance and to relax the implementation of the new technology.

Moreover, Ulrich and Brockbank (2005) indicated that involving different levels of employees and human resource professionals in planning and executing the change process is prudent for a sustainable and consistent transition. According to Rouda and Kusy (1995), involving all levels of employees in identifying the goals of the change and classifying the required actions can help avoid resistance from staff members, while uncovering different problems that higher-level managers may not consider but still have an impact on the transition. Also, leadership committed to the change and able to lead by example and communicate with different participants is a key component to drive the transition phase (Fernandez & Rainey, 2006). Strong leadership will ensure that the required goals are attained and a stable position is reached throughout the whole organization once the organizational change is complete (Burke & Ng, 2006).

Kotnour (2011) found that having a well-defined change management model, which is systematic and suited with organizational change goals, will reduce the resistance to change, uncertainty during change, and employee burnout, leading to a smooth transition. Change management methods or models help managers engineer their organizational change process to take into account the overall organizational strategy and objective by establishing a vision and plan able to involve different stakeholders into the change process (Grover, 1999). Several change models have been proposed in the literature and were based on the principles of sociology and strategic change theories (Worren, Ruddle, & Moore, 1999).

One of the first organizational change models was introduced in 1947 by Kurt Lewin. This model was demonstrated in the book, *Field Theory in Social Science* (Lewin, 1951). This model consists of three main steps: unfreezing, changing, and refreezing. In the unfreezing step, the present stable environment in an organization is being altered by the newly introduced changes. The changing step involves analyzing the barriers and driving forces that will impact the transition process. Once the organization has reached a new stable state, and workers are accepting the organizational change by working through the new tasks and daily routine, then the refreezing phase should take place. Conducting a celebration where workers feel appreciated for their part in the successful change can help in stabilizing the new state and building a new sense of hope (Ritchie, 2006).

In 1969, Richard Beckhard developed a change model consisting of four main tasks (Beckhard, 1969). The first task focuses on clearly identifying the desired goals and rewards from the organizational change. Then a detailed diagnosis of the current condition has to be conducted with regard to these goals. The third task requires defining the role of each employee and the activities required for this transition to succeed. Finally, a management strategy is established to monitor the progress of the transition and identify any barriers slowing down the process. Dunphy and Stace (1988) argued that a change model should depend on the organization's leadership style. They also provided a change model that focuses on two dimensions: the scale of change and the leadership style.

In the early 1990s, Judson (1991) presented a change implementation model to avoid resistance to change; the model consisted of five main phases: 1) analyze the change required, 2) communicate this change, 3) gain acceptance among the staff, 4) perform the change to reach desired outcomes, and 5) consolidate the change. Judson (2011) found that predicting the sources of resistance before it occurs and providing different media of communications and bargains can facilitate the change, avoid resistance, and increase staff readiness to change. Following Judson (1991), Kanter, Jick, and Stein (1992) provided a sequential process for managing change. In this model, leaders had a role in identifying the external and internal sources that can slow down the organizational change in order to face them and present them to the main stakeholders.

One of the most famous organizational change models is the “leading change” model, which was developed by Kotter (1995) and has been under continuous development since then (Kotter, 1995, 2012). This model was one of the key aspects that helped us develop our interview questions and discuss the necessary steps for a successful organizational change with participants. One of the advantages of this model is that it includes eight comprehensive and clear steps, which makes it relatively easy to understand, implement, and control. The eight systematic steps are as follows (Kotter, 2012): 1) establish a sense of urgency, 2) assemble a group of people with enough power and influence to lead others thorough the transition, 3) develop a vision and a strategy, 4) communicate the vision, 5) implement serious actions that can help remove obstacles and facilitate change, 6) create short-term goals to help track the transition process, 7) consolidate gains and encourage further improvements, and 8) anchor new approaches in the organizational culture while showing the successes that the organizational change was a reason for.

Furthermore, Luecke (2003) believed that strong leadership during change will allow staff members to see change as an opportunity not as a threat to their comfort or careers. The Luecke method depends mainly on participation of all staff members and communication. The method encourages identifying a shared vision among employees and identifying the problems and solutions to reach this vision, and finally implementing the action plan while monitoring it during the change process. Also, in the early 21st century, Hamel (2001) presented a change model that aims to provide clear steps for radical and large-scale changes in organizations. The model recommends writing the policies of change and making them clear among employees in the organization. In our interviews, we focused on finding if participants agree with some of these factors that can facilitate change and what other factors they consider can help drive a successful and smooth transition process

4. METHODOLOGY

To address our specific research objectives, given the practical and exploratory nature of our study, we selected a qualitative research method that involves interviews and questionnaires. The aim of this methodology was to help us gain in-depth descriptions and insights from a variety of DOT employees about how to improve current bridge inspection practices and facilitate the implementation of new research findings and technologies in DOTs.

4.1 Research Questions

The investigation protocol was developed to address the following research questions:

- Research question 1: What do bridge inspection professionals think about the current bridge inspection practices and how can the quality of inspections be improved?
- Research question 2: What are the actions that can be taken by researchers and DOTs to help improve the effectiveness of research products in the bridge inspection field and promote their utilization?
- Research question 3: What are the factors that should be considered from an organizational change perspective that can help accelerate research implementation in bridge inspection practices?

The research questions are strongly connected with the study objectives. The first research question addresses our first objective, which is analyzing the current situation in bridge inspection practices by investigating participants' opinions on some of the aspects related to bridge inspections. In addition, our second objective is to understand how research products can be improved in the bridge inspection field, which links with our second research question. We developed our third research question to identify the factors that can facilitate change in transportation organizations from an organizational perspective, and that is the third objective of this study.

4.2 Participants

Staff members in public organizations can perceive innovation and change differently depending on their position and responsibilities (Fernandez & Rainey, 2006; Savage, Nix, Whitehead, & Blair, 1991). Accordingly, we aimed for a maximum variation sample of key personnel in the organizational structure of state DOTs' bridge management divisions (Creswell & Poth, 2016). The goal of the sampling approach was to provide us with different perspectives to fully describe how different managerial levels and staff members could contribute to research implementation and organizational change. The participants represent the organizational members that will be involved in any change in the bridge inspection programs. The participants will either be involved in the planning phase, execution phase, or both. In our investigation, we sought responses from three main levels of employees or job positions with the following criteria:

- Level 1 (L1): A bridge program manager in the DOT who is responsible for approving new inspection techniques, new funding, hiring consultants, research, communicating with the FHWA, and deciding on the training programs for inspectors.
- Level 2 (L2): A senior bridge inspector in the DOT who 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): An assistant bridge inspector in the DOT who conducts the bridge inspection and prepares the inspection report.

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. For example, in one DOT, the level 1 manager is named a bridge asset manager, while in another DOT the same position is named as bridge program manager.

Individuals invited to participate in the study were identified from the DOTs' websites and from professional connections of the authors. We then emailed participants asking them to participate in our study and telling them the reason they were chosen and the possible risks and benefits. A consent form was obtained from participants before participating in any part of the study, and participants had the option to withdraw from the study at any time without penalties.

4.3 Data Collection

To obtain rich answers for our research questions, the investigation protocol consisted of four main data collection methods: "Bridge Inspection Questionnaires," "Journal Articles Interviews," "Organizational Change Interviews," and "Written Interviews." Also, to broaden the range of the viewpoints and to make sure that participants are answering questions related to their responsibilities and managerial level, each data collection method involved different job levels or positions (L1, L2, and L3). Before starting our data collection process, we obtained institutional review board approval from Colorado State University.

Bridge Inspection Questionnaires: The value of bridge inspections depends on the time of inspections, inspection method, and quality of inspection reports (Emal, 2017). Also, the first step to implement change and innovation in organizations is to analyze the current situation and the changes required (Fixsen et al., 2005; Judson, 1991). Therefore, the Bridge Inspection Questionnaires were developed to gather information about current inspection practices and how DOTs plan and conduct inspections and what participants think can help improve current inspection practices. The questions also focused on understanding how bridge inspection planners use inspection data in their decision process. The questionnaires were self-administered and consisted of six open-ended questions found in Appendix (A). The Bridge Inspection Questionnaires were sent by email to L2 and L3 participants only.

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 (Schultze & Avital, 2011). To do so for this study, the participants received by email three journal articles that discuss three different strategies for bridge inspection planning. These articles represent a small but representative sample of the research that has been done in the field of bridge inspection. With this approach, our 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, since our participants are mainly experts in the field of bridge inspection. Then in the journal article interviews, our discussions focused on identifying the concerns or questions participants found in these articles that can be generalized to other research products in the transportation sector.

Each journal article discusses a different inspection planning strategy, has been published in prestigious journals in the civil engineering field, and has been cited numerous times. The first article was published by Washer et al. (2016a) and presents a risk-based inspection planning framework based on the NCHRP 12-82 study (Washer et al., 2014). The second article discusses an inspection planning framework proposed by Kim and Frangopol (2011). The framework uses optimization algorithms and decision trees to choose the optimum inspection time and method that will minimize maintenance delay and inspection cost. The third article focuses on using the probability of detection in choosing the appropriate inspection interval for different NDE tools. The study was written by Chung et al. (2006) and focused on inspection planning for steel bridges. Appendix (B) contains a summary of each article. The articles were sent to the participants along with a brief summary of each article before the interview.

The interviews were 45 minutes 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. Also, in the journal article interviews, we 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, since both of these topics were also discussed in the journal articles sent to participants.

Organizational Change Interviews: According to Oreg, Michel, and By (2013), designing a successful change framework starts by analyzing the views of those who have previously experienced change in their organization. Also, organizational change models, such as the ones discussed in the Background section, provide systematic frameworks for organizations to follow during change. However, Rosenbaum, More, and Steane (2017) pointed out that these models are not comprehensive and change leaders need to recognize other change drivers or barriers that could be specific to their organizational culture and still have significant impact on the transition process.

Therefore, in the organizational change interviews, we asked participants about their past experience with organizational change and the factors they think can facilitate change and research transfer in bridge inspection divisions. Our questions tried to analyze if the participants agree with the factors mentioned in some of the theoretical change models (Judson, 1991; Kanter, 1983; Kotter, 1995; Luecke, 2003) and if there are other factors DOTs need to be aware of. The organizational change interviews were also semi-structured interviews to understand how different organizational contexts informed the participants' responses to the interview questions. This part of the study included all levels of participants to understand how different staff members in the organizational hierarchy perceive change. We also used this advantage (involving all participants) to ask participants directly about the reasons behind the gap between research and the industry, and the research topics researchers should focus on.

Appendices (C) and (D) contain the questions asked during the journal article interviews and the organizational change interviews. All interview questions were sent to participants before the interviews. All journal article interviews and organizational change interviews were conducted in a private setting with participants either using video conference or telephone conference due to the COVID-19 pandemic. Some of the interviews were audio recorded with the participant's consent as a basis to develop detailed transcripts. For those interviews not recorded, investigators took notes of participants' responses.

Written Interviews: Due to the tight schedule of employees working in the DOTs, it became apparent that it was difficult to schedule the phone or video interviews. Accordingly, to increase the response rate, we prepared a written format (written interviews) of the most critical parts and questions of the bridge inspection questionnaires, journal articles interviews and organizational change interviews that were central to our research objectives. The questions added to the written interviews were based on our preliminary analysis and the quality of the responses in the journal article and organizational change interviews. The written interviews consisted of mostly open-ended questions and were sent out anonymously using Qualtrics to participants who we believe are L1 and L2 employees in different state DOTs, but we cannot for sure verify if it was only L1 and L2 employees who responded as this was an anonymous process. In the written interviews, participants were provided only a brief summary of the first journal article to save time. The participants were then asked if they will consider applying a similar inspection planning approach in their department and what will be the required resources and potential obstacles to implement new ideas in inspection programs. The anonymous written interviews did not contain any questions that can identify the participants. Appendix (E) shows the questions asked in the written interviews.

We reached data saturation and all the data were stored on password protected computers only accessible by the authors for confidentiality. A total of 26 DOT staff members participated in this study, consisting of 19 anonymous participants, three Level 1 managers, and two Level 2 and two Level 3 staff members. The response rate to the written interviews was significantly higher than other parts of the study. Table 1 summarizes the number of participants involved in each data collection method.

Table 4.1 Data collection methods and participants involved

Method	Purpose	Participants
Bridge Inspection Questionnaire	Gather information on current inspection practices	Two L2 and Two L3
Journal Article Interview	Discuss the three journal articles and some aspect related to current practices such as the 24-month inspection cycle and NDE methods	Three L1 and two L2
Organizational Change Interview	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	Nineteen anonymous L1 and L2 participants

4.4 Data Analysis

Two researchers were present for all interviews. Interview data were transcribed and analyzed along with the participants' written responses using thematic analysis (Braun & Clarke, 2006). Minimum 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 the 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 interpretation in our respective analysis, and to make sure we were answering our research questions. The literature review and data collection methods both helped us answer our research questions, as shown in Figure 4.1 and explained in the following sections.

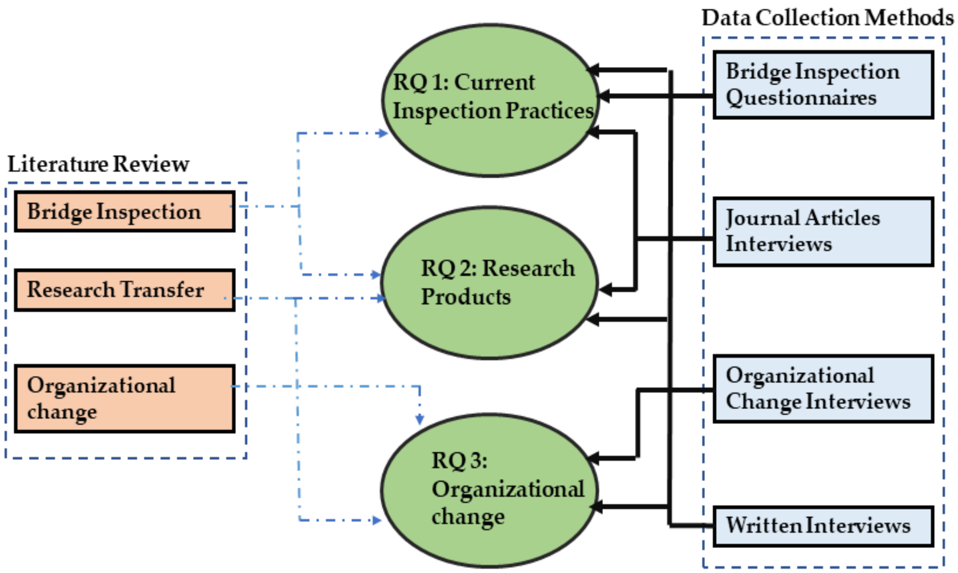

Figure 4.1 The contribution of the literature review and data collection methods in answering the research questions

4.1.1 Research Question 1

The Bridge Inspection Questionnaires helped us identify the approaches DOTs currently use to schedule bridge inspections, evaluate bridge performance, and manage inspection data. Also, L2 and L3 participants provided us with some important insights on how to improve current inspections from their perspective. In the literature, researchers pointed out several limitations associated with conventional bridge inspection practices. Thus, the journal article interviews and the written interviews helped us analyze if practitioners in the bridge inspection field agree with researchers on these limitations, especially the ones related to the 24-months inspection cycle, visual inspections, and NDE methods. The Bridge Inspection Questionnaires, the Journal Articles and Written interviews helped us identify some of the gaps between researchers and practitioners in the bridge inspection field.

4.1.2 Research Question 2

The journal article interviews and the written interviews also helped us understand if bridge inspection professionals will be willing to apply different inspection planning frameworks such as the ones provided in the journal articles and what will be the barriers, requirements, and advantages for implementing new frameworks and ideas in current bridge inspection programs. Our discussions helped us identify how researchers and DOTs can work together to improve research products and find applicable and practical solutions for important problems in the field.

4.1.3 Research Question 3

The organizational change that we focused on in this study is intended to facilitate the implementation of new inspection planning frameworks and technologies in bridge inspection programs. The organizational change interviews and part of the written interviews helped us explore what participants thought are the main reasons for a successful organizational change based on their experiences with DOTs. This helped us identify the potential facilitators and barriers of change that will face new innovations and transitions in DOTs and map them with the evidence found in the organization change literature. Also, this part of the study helped us analyze the differences and commonalities between the participants' perspectives on organizational change, and how different managerial levels and employees with different authorities and responsibilities can embrace or resist change.

4.2 Quality Assurance of Findings

Forms of triangulation were conducted on parts of the data involving all three authors to enhance credibility and dependability (Jonsen & Jehn, 2009). 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 (Creswell & Miller, 2000). Continuous discussions involving all three authors were conducted to decide on the main study themes and to reach consensus agreement on every theme and relations between themes. This process contributed to the trustworthiness and quality assurance of the findings (Elo et al., 2014).

5. FINDINGS

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) 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. Themes 4 and 5 helped us answer our third research question regarding the factors that can help facilitate change and research implementation. Each theme consists of subthemes and, as shown in Figure 5.1, the solid arrows represent the connection between the themes and the research questions (RQs), while the dotted arrows represent how some subthemes provide a secondary contribution in answering other research questions.

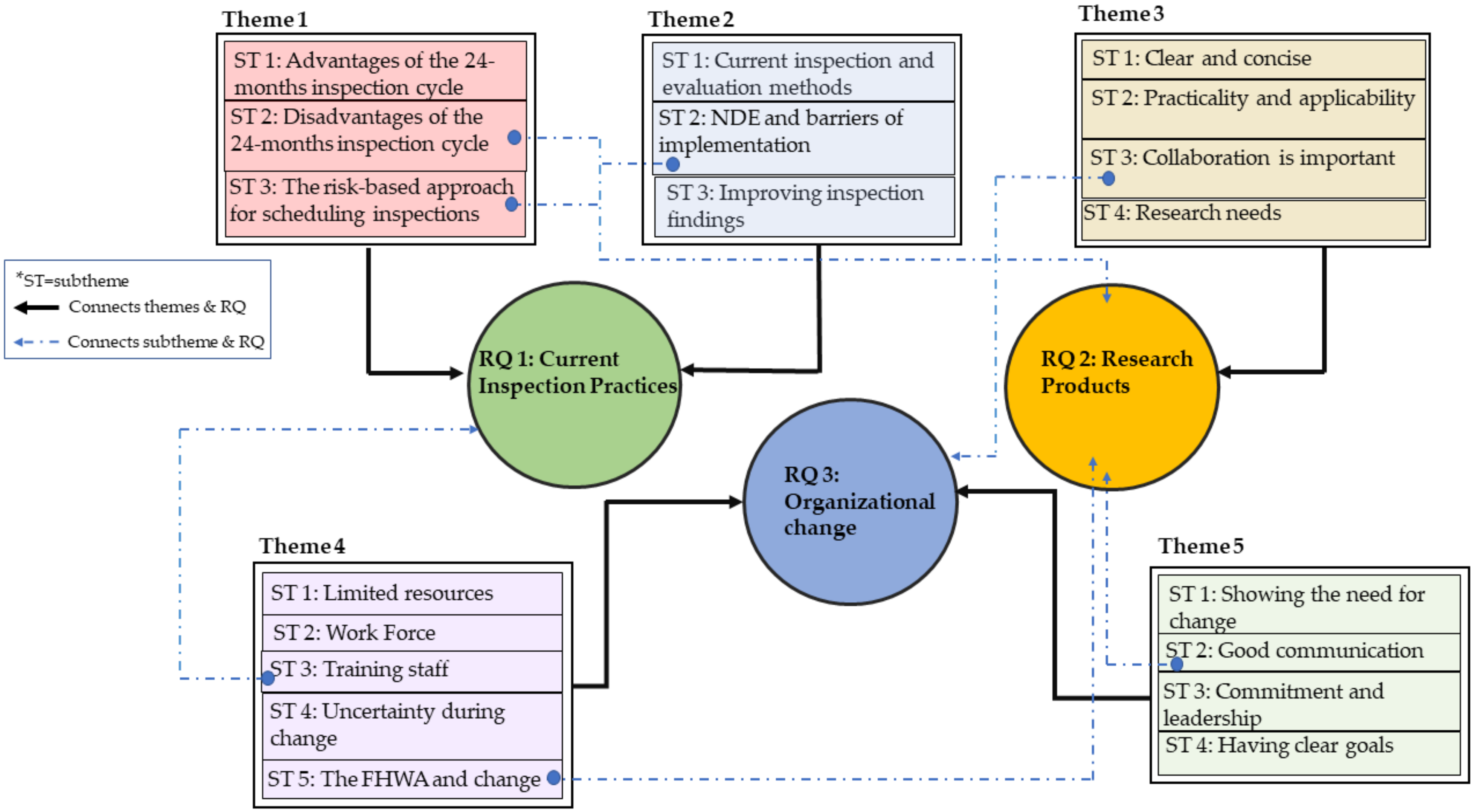

Figure 5.1 Themes and subthemes and their connection to the research questions

5.1 Theme 1: The 24-Month Inspection Cycle

In our interviews, 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. 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. The 24-month inspection cycle used to schedule routine bridge inspections has been the focus of many researchers seeking to enhance the efficiency of bridge inspection practices. In our investigation, we found that 44% of the participants supported the 24-month inspection cycle, 24% were against it, and the remaining 32% stated that it has some advantage and disadvantages.

5.1.1 Subtheme 1: Advantages of the 24-month inspection cycle

Some participants reported that the uniform 24-month inspection interval 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). While 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). Also, 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).

From another standpoint, participants considered the 24-month cycle as a safe approach for scheduling inspections: "The fixed interval ensures that bridges are inspected in a generally conservative interval, and that has a proven record of effectiveness" (Anonymous participant); "Some bridges could be moved out from the 24-month cycle, but I would prefer to know sooner than later for issues that need to be addressed on the bridges" (Anonymous participant). Several participants commented on how the 24-month cycle helps in tracking bridge deteriorations: "It helps letting our personnel stay familiar with their group of bridges to understand which ones need more attention or which ones are deteriorating faster. I understand the budgetary advantages of going to longer inspection intervals on good bridges, but for the vast majority of bridges in good to fair condition, 24 months is the right time to stay in touch with the bridge's behavior" (Anonymous participant).

The simplicity and consistency of the calendar-based approach in scheduling inspections was also mentioned. Some participants found it a clear approach for scheduling inspections that does not require complex analysis: *"It is simple and uniform across the board which makes it easy to remember with no chances to miss due to mixed rules"* (Anonymous participant); *"Provides a clear starting point for each structure in the inventory"* (Anonymous participant).

5.1.2 Subtheme 2: Disadvantages of the 24-month inspection cycle

On the other hand, some participants thought the fixed inspection cycle is a waste of resources and does not suit every bridge condition: "*A one-size-fits all model for inspections can be an inefficient use of resources, inspection resources should focus on the bridges that need it most and back off from those where it has little added value*" (Anonymous participant); "*For bridges with NBI condition rating greater than 6, this could be considered a too frequent requirement and extending frequency will free up resources for other structures*" (Anonymous participant).

Some participants stated that the inspection cycle should be extended, especially when the bridge is new and is in good condition, and then it can be adjusted as the bridge performance drops and deterioration rate increases: "*Routine inspections should be performed after the initial inspection at an increased frequency to begin with and if there are no identified issues, I think the frequency should be reduced to at least 4 years or more until it reaches either an actual or predicted deterioration level that may warrant an increased frequency*" (L1 employee); "*New bridges in good condition are being inspected with little benefit because condition changes slowly in the beginning of the life of a bridge* " (Anonymous participant).

Two participants mentioned that the 24-month cycle limits the inspection findings and quality due to weather conditions, because inspections for a bridge will happen in the same weather conditions every time, which might limit inspection and the analysis of the bridge performance: "*Performing inspections on a 24-month cycle (in the same calendar month) results in very similar environmental conditions during the inspection. For example, the inspection may occur during the* '*rainy season*' *so chain dragging the deck is not commonly performed as part of the routine inspection. Likewise, scour and sediment transport processes can vary by season. A greater variety of conditions may be observed if the inspection cycle was changed to 24 months plus or minus 3 months"* (Anonymous Participant).

5.1.3 Subtheme 3: The Risk-Based Approach for Scheduling inspections

In the participants' responses it was clear that most of them were concerned about the upcoming updates of the NBIS and the risk-based approach for scheduling inspections, which the FHWA is considering as a second option for scheduling inspections (FHWA, 2019). This approach is relatively similar to the framework presented by NCHRP 12-82 study (Washer et al., 2014), which was explained earlier in the Methodology section. An L2 participant stated that the main reason for this transition was the pressure the FHWA has received from the DOTs: *"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 FWHA going more with risk-based systems with load ratings, and risk-based guidelines; they are going down that road"* (L2 employee).

Participants shared their thoughts on the risk-based approach: 36% said they will apply it once it is allowed, 21% said they will not consider it, and 43% indicated that they will wait and see how other state departments will apply it: "*We are not going to deal with trying to figure it out, we are just going to do them on a 24-month base and wait for others, we are very conservative here we don't want to be the first ones to do anything because we might mess it up*" (L2 employee).

An L1 manager commented that the reason they will consider applying risk-based inspection timings in their department is that the new approach will help in managing resources and improving inspection quality. "*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); while another L1 manager said that they will not consider applying the approach also for managerial reasons and that most of their bridges will still need to be inspected after 24 months: *"We will not apply it because it will be hard to group aging bridges together and variable inspection intervals will be hard for budgeting. We also looked into similar approaches, and it turned out that most of our bridges in our inventory will need to be inspected every 24 months"* (L1 employee).

When we asked the participants about the obstacles and resources for specifically applying the risk-based approach, they commented on the risk-based panel that needs to be established to choose the inspection intervals and the effort and time it will require: "*Taking time away from bridge inspectors to sit on a panel is not achievable. The FHWA requirements for inspection frequencies necessitate that the inspectors are inspecting bridges not attending meeting to determine if a bridge can be moved to a different frequency"* (Anonymous participant); "*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).

Other participants shared their concern regarding the data that will be required to implement a risk-based program: "*We would need a project to review our historical bridge records to determine which elements, which conditions, and which component ages would drive the inspection intervals. Setting the intervals needs to be data-driven and not just based on judgment of the local inspectors and program managers*" (Anonymous participant). Also, some shared their concern regarding the effort and time that will be required to establish the risk-based frequencies: *"Creating this program will cost significant cost and employee time. The research for the basis of the intervals for our specific state elements has not been done and will need to be created from our historical data, and the program RBI intervals will need to be updated regularly"* (Anonymous participant). The FHWA was also mentioned several times by participants who were concerned by its approval on the inspection intervals: *"Once the new intervals are created, they need to be approved by the FHWA and since the FHWA does not give clear guidance on what is an acceptable approach to RBI, it is unclear how long our proposed approach would remain acceptable to the FHWA before they require us to redo a brand new RBI project to reset our intervals using a method that is acceptable to FHWA"* (Anonymous participant).

5.2 Theme 2: Evaluating Bridge Performance

The second part of our analysis of current practices focused on understanding how bridge conditions are evaluated, and what participants think about NDE techniques. Under this theme we also explore what decisions can be made based on the inspection findings and what can be done to improve the value of inspection data.

5.2.1 Subtheme 1: Current Inspection and Evaluation Methods

We discussed with participants the techniques they use during inspections, all participants confirmed that visual inspection is the primary method used during routine inspections, while in some routine inspections chain drag can also be used: *"Typically we just use visual inspection techniques during a routine inspection, and we will commonly do deck chaining and sounding with a hammer during our routine inspections"* (L2 employee). For some steel bridges during routine inspections, other NDE methods such as magnetic particle and dye penetrant test are used. However, most participants stated that NDE methods are mainly used during in-depth inspections. Also, tools such as snoopers and man-lifts can be used for accessibility.

The value of the information provided from visual inspections has been addressed in the literature in several occasions, along with its reliability and impact on the decisions and management process of the bridge life cycle performance (Graybeal et al., 2001). Some participants commented that one of the main uses of routine inspections is to check on the safety of the bridges and the critical issues: *"The primary purpose of the routine inspection is to assure that the structures are safe for the traveling public and can remain in* service" (L3 employee). An L1 manager stated that routine inspections can be used to determine the amount of work or repairs that need to be done on the bridge *"We use the inspection information to assist with determining what type of work needs to be done on a bridge as well as determining the best time to do the work"* (L1 employee). Other participants stated that routine inspections help in determining if an in-depth inspection will be required or not. Also, in some cases, routine inspections and bridge ratings can help in determining if the inspection cycle needs to be reduced or not: "*Routine inspections and coding of the NBI can show the urgency if tighter inspections cycles are needed"* (L3 employee).

As mentioned earlier, there are two systems to rate the bridge performance during routine inspections, the NBI rating system (Guide, 1995) and the AASHTO element level system (AASHTO, 2013). Almost all participants commented that they use both systems to report the bridge condition. They use the NBI rating system to rate the main bridge components, such as the super-structure and the sub-structure. The NBI rating is based on the element level rating of the elements, which form the main bridge components. The inspection data and bridge ratings are managed using a bridge management software; 78% of the participants use AASHTOWare (previously known as PONTIS) (Thompson, Small, Johnson, & Marshall, 1998), while 22% use other in-house programs. An L1 manager commented: "*We use NBI and Element data to evaluate all of our bridges. We plan to use Element data more and more as it becomes more consistent and reliable. It certainly is the goal. We use AASHTOWare for analysis*" (L1 employee).

5.2.2 Subtheme 2: NDE and Barriers of Implementation

NDE has been recommended as a tool to improve the quality of inspections, however its use has been hindered in practice. Some participants commented that the main barriers for using NDE more often during inspections are the training required by bridge inspectors, maintenance of traffic, cost of equipment, and accessibility required to reach certain bridge locations. An L2 employee mentioned some of these barriers as the following: "*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. I think NDE methods are more appropriate for more in-depth inspections, we do visual inspection to identify cracks and we use NDE to confirm on them*" (L2 employee). Also, an L3 employee added that NDE methods can be expensive and time consuming. Some participants mentioned that most of the NDE inspections are done by special consultants hired by the DOT.

5.2.3 Subtheme 3: Improving Inspection Findings

Participants commented on the quality of inspection reports and data and how it can be improved. Some of the participants agreed that inspectors' training is the most important action that can help in enhancing the value of 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); *"We need to improve the training, knowledge and competence of the inspector"* (L3 employee). Some participants mentioned that having a consistent inspection protocol can help increase the accuracy of inspection findings: "*It is helpful to provide consistent inspection procedures and guidance*" (L2 employee); while one participant suggested that inspection effort and quality should depend on the bridge condition to optimize inspection efforts: *"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).

Further, two participants mentioned that improving inspection equipment and introducing new technologies can help improve the evaluation process of the bridge condition: *"Advancing technologies that provide reliable data suitable for condition assessment is a strong key improvement to improve bridge inspections for the future. Imaging technologies, automated quantification of defects, technologies to gain challenging access are some of the improvements that are needed over present methods"* (Anonymous participant).

5.3 Theme 3: Effectiveness of Research Products

One of our goals in this study was to identify the attributes that can help improve the research products in the field of bridge inspections. This theme covers what the participants find are the main factors affecting the quality of the research presented and hindering its implementation, such as not providing clear and concise research results, applicability of research only on special bridge cases, and how collaboration between DOTs and researchers can help reduce the lag between research and the industry.

5.3.1 Subtheme 1: Clear and Concise

Many participants agreed that sometimes research ideas are confusing and hard to understand, which makes it difficult to implement. This was clear from their comments on two of the journal articles, which participants found hard to analyze: *"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's 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). An L1 manager commented that one of the reasons that prevent applying new ideas is that managers cannot permit something in their departments without being able to understand it or explain it to other staff members: *"Very hard to understand this paper because of the statistics, it is hard to follow. I have to learn it in order to be able to explain it and I cannot present something new that I don't understand"* (L1 employee).

Also, it was clear during our investigation that most participants have tight schedules and no time to read the journal articles. In some cases, participants did not want to schedule interviews that will involve reading the journal articles. An L1 manager, who feels that one of the main obstacles to be updated with research findings is time, commented: *"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 to their program"* (L1 employee). Other participants shared their concern regarding the time that will be required to reflect on a new technology or an inspection planning program and understand how to adapt it.

Several participants recommended that researchers should focus on providing clear and practical ideas that can help DOTs solve some of their problems: *"Provide clear, concise, and deployable guidance. Guidance must be practical, understand the demands of the bridge inspector"* (Anonymous participant); *"Provide ideas on emerging and promising technology, but research needs to be directed towards ideas that can be implemented by the DOTs with the limitations they currently have"* (Anonymous participant).

5.3.2 Subtheme 2: Practicality and Applicability

During our discussion with an L3 employee, he noted that another problem with research products is that sometimes research ideas are impractical and cannot be applied on a whole bridge network: *"As far as implementing the stuff you guys come up in the lab well some of these stuffs are awesome but applying it to thousands of bridges statewide seems impractical"* (L3 employee). He added that in order for researchers to be more practical they need to come to the field more often and see what is really happening on site.

An L1 and an L2 participant mentioned that one of the main problems regarding two of the journal articles is that they are only applicable on specific deterioration modes or types of bridges, and cannot be generalized: *"I don't think it would make any sense to apply this idea on the whole network because we are talking about very limited items; because if you are talking about the whole network for instance, we* *have very few fracture critical elements"* (L2 employee); *"This planning framework works for one deterioration process only; which is an incomplete analysis for a bridge"* (L1 employee)

5.3.3 Subtheme 3: Collaboration Is Important

Several participants agreed that collaboration between practitioners in the industry and academics can help improve research products and direct research efforts efficiently. Participants found that academics should engage personnel from the industry in their research programs to help them more quickly find practical solutions for problems that truly exist in practice not just in theory: *"Continue with your research, one research outcome could be the answer to everything. During the research, engagement with bridge inspectors and program managers performing the work will lead to a more reasonable research outcome. Presentations of research findings to bridge owners could help"* (L1 employee); "*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. I think communication is the biggest thing that is going to help*" (L2 employee). Two participants suggested that researchers could conduct workshops or training sessions for bridge inspectors to help them understand new ideas and research findings. They suggested that these sessions can be through workshops, organized conferences, or even online: *"Deliver active training/webinars through AASHTO or similar established organizations"* (Anonymous participant).

Also, staff age can influence collaboration and research implementation. A senior inspector mentioned that in some cases older staff members might resist getting involved in new technologies and understanding them, unlike young staff members who might be willing to try new ideas: *"There is a gap between old guys like myself and somebody coming out of college. The people coming out of college are more into technology or a lot more willing to accept it. I still want to get out and look at the bridge, there are guys coming out of college that would be ok for forming a circuit camera or centers, or something telling what is going on. Get rid of all us dinosaurs"* (L3 employee).

5.3.4 Subtheme 4: Research Needs

Several research ideas were suggested by participants as areas for researchers to focus on. Some participants complimented the research going into drones and how promising they find it: *"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. An L3 inspector also suggested that academia should focus on helping bridge managers estimate the life cycle of bridges, especially new bridges constructed using new materials and technologies. Some participants also talked about finding better methods to link between the element level rating system and the NBI rating system: *"We need a link between element data and condition ratings (NBI components), we also need new technology to more accurately estimate element level data and link it to locations"* (Anonymous participant).

5.4 Theme 4: Change Barriers

Many participants agreed that applying a new inspection program or implementing a new technology in the bridge inspection department will require organizational changes and preparations. Participants helped us understand the challenges that a DOT will face during a change and the aspects that can help make the transition successful. This theme presents some of the barriers that participants faced or expect to face during an organizational change.

5.4.1 Subtheme 1: Limited Resources

Several participants commented that change can help save resources, but at the same time is not cheap and most research ideas, such as the ones presented in the journal articles, will require funding and resources that are not available to all departments, especially since most DOTs have a very tight budget: *"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); "*You can chain drag a deck and reach the same conclusion as thermal modeling or GPR. It is tough to throw that extra money at the new technology until all the federals say you have to use that*" (L3 employee). Some participants commented that one of the barriers they found while reading the journal articles is that some of the frameworks require software and several pieces of NDE equipment that are either not available to their department or will require funds to purchase.

5.4.2 Subtheme 2: Workforce

A participant noted that applying a new inspection planning program will require personnel that might be limited in most DOTs: *"I think probably the biggest challenge we are going to have right now is that we are already challenged with having enough staff. We are very lean staff and whenever there is changes it requires up front time and effort to get those things going and to implement anything. I think that is going to be one of the big things"* (L2 employee). Some DOTs that hire consultants to do inspections thought that a new inspection program will require either revising contracts with consultants or hiring new ones.

Two participants commented that a variable inspection planning program might lead to downsizing or hiring new employees, which can be a challenge for the organization's stability and needs to be considered: *"Adjusting the schedules and cycles based on the condition of the bridges will only in the future narrow down the time between inspections and keeping the workforce levels consistent to provide the inspections needed will vary from year to year, and hiring employees or downsizing employees is not an easy task"* (Anonymous participant). Another participant suggested developing resource models to help manage the personnel changes: "*Resource models to establish and balance workload would be needed. These models may predict personnel changes. Basic organizational structure will probably be about the same"* (Anonymous participant).

5.4.3 Subtheme 3: Training Staff

Three participants stated that training inspectors and staff to adapt to a new technology will be the main challenge during transition: *"The biggest obstacle in implementing a new technology is always having dedicated personnel that can be trained to understand it. There is always less and less personnel in state DOTs performing a very wide range and ever-growing list of duties; so, taking onto technology or processes that do not provide immediate benefit would hurt the program in the short term and may cause those employees to look very poorly to their management"* (Anonymous participant); *"We will need to train our managers and inspectors on the new approach to setting the inspection intervals. They will need to know how their work affects the intervals. We will need to set up protocols to check that intervals are being reset properly and when they should be"* (Anonymous participant).

Some participants commented on the updates that will be required in the bridge management system if a new inspection planning program is to be implemented and the staff training that will be required to adapt to the new system. They noted that an updated bridge management system or software can help organize inspection schedules and even select inspection intervals based on the bridge condition: *"We will need to update bridge management systems and the standards that flag upcoming due inspections"* (Anonymous participant); *"We can customize deterioration models and network policies in bridge management* *software; and utilize the software in determining inspection intervals based on actual or predicted performance"* (Anonymous participant).

5.4.4 Subtheme 4: Uncertainty During Change

Some participants reflected on their previous experiences with organizational changes in their departments. Most of them mentioned that one of the main challenges they found during the time of change was uncertainty about the new change and how this change will affect them: *"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 is a lot of uncertainty throughout the state"* (L3 employee).

4.4.5 Subtheme 5: The FHWA and Change

Several participants stated that convincing upper levels of management and the FHWA that a change is required is one of the main challenges to start an organizational change. An L1 employee stated: *"Convincing management and the FHWA that organizational changes were necessary was probably the biggest barrier"* (L1 employee). An L3 inspector talked about how his department wanted to conduct a change in their inspection schedule but were faced by FHWA regulations, which made the change expensive to implement: *"We were going to do 48-month inspections for 70% of our in-state bridges. However, the FHWA wanted us to perform an in-depth inspection on every bridge before we put it on there. So, it was cheaper for us to continue doing inspections every two years then doing an in-depth inspection. A lot of what state organizations do is highly regulated by the Federals"* (L3 employee).

An L1 manager mentioned that one of his concerns about applying a new inspection planning program is that there will be no help or guidance from the FHWA, and the DOT will be left responsible for all of the change process: *"My fear is that it could end up being just one more thing that the states will be responsible to develop and implement on their own by a certain date when we have limited resources available and numerous other challenges to overcome"* (L1 employee).

In addition, an L2 employee used one of the journal articles as a reference and commented that before allowing a new inspection planning program the FHWA must be able to evaluate the performance of the DOTs under this new program and must be sure that this program will not affect the safety of the bridge network: *"It will be hard for FHWA to determine if you are inspecting the bridges on time. They already have a set of metric reviews they use to make sure you are doing what is supposed you should be doing. They have to approve and evaluate each of those statistical analyses and figure out if you are calculating the frequency correctly; probably that will be a hard sell to the FHWA"* (L2 employee).

5.5 Theme 5: Change Facilitators

This theme demonstrates what participants mentioned as the factors that can facilitate change based on their previous experience with DOTs. Some of these factors, such as showing the need for change and staff communication, are strongly connected to what is mentioned in the organizational change literature as change facilitators or enablers.

5.5.1 Subtheme 1: Showing the Need for Change

Some participants found that in a public organization such as the DOT, to promote change and involve staff members in the organization you need to clearly show the benefits and necessity of the change. An L2 employee stated, *"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. Showing that these are really beneficial changes will make things better, more efficient and help things function better"* (L2 employee). Also seeing improvements along the change process can help keep the momentum and the motivation of the staff as mentioned by some participants.

Some participants during their discussion stated that organizational changes in their division started because there was a need for it. For example, one of the DOTs investigated initiated a change because the quality of its inspection data was not as required by the FHWA and change was necessary: *"Quality of inspections was deficient. This triggered Plans of Corrective Action (PCAs) from FHWA which helped convince upper management changes were necessary to meet FHWA metrics"* (L1 employee); *"It was really challenging for the reduced staff to stick to a 24-month schedule and because of that we found that we were not getting really good inspections and we were not meeting timelines"* (L2 employee).

5.5.2 Subtheme 2: Good Communication

Some participants noted one of the main factors that led to a successful change in their department was good communication among staff members. Some participants mentioned that having weekly meetings and being able to reflect on what is happening and what needs to be improved helped during transition: *"Our goal was to have weekly discussions to help us monitor the progress we are doing and share insights and experience, share ideas, issues and try to solve issues so we can still progress forward with our team"* (L3 employee). An L2 manager mentioned that during a successful transition in their department, managers were really keen on interacting with inspectors to help them understand the reasons for the change and be prepared: *"This is one of things that we really tried to do, is to help them understand why they are doing what they are doing. I think if this change makes sense to them, it would help them do a better job"* (L2 employee)

5.5.3 Subtheme 3: Commitment and Leadership

Several participants mentioned that for a successful transition to take place, staff members throughout the entire organization have to be dedicated to the change. An L1 manager stated that one of the main reasons for a successful organizational change was the dedicated staff: *"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). Other participants commented on the importance of leaders during the change and their ability to make a decision. During our discussion with an L3 inspector, he stated that what made the change successful is that someone made the decision: *"At the state level, pressure comes from the top down if you can get the bosses on board that's how it would work. What made the transition happen honestly is that somebody actually made a decision, they wanted to go in that direction, and they went, and it was amazing"* (L3 employee).

5.5.4 Subtheme 4: Having Clear Goals

We asked the participants if they thought having short-term goals can help manage an organizational change and implement new ideas and technologies. Some of the participants agreed, and an L3 inspector commented: *"I think starting out with some short-term goals will give us the groundwork to kind of taking those necessary steps to build that program to what we see fit. I think we would see where we are at, and kind of have some measurables to monitor if we are meeting our monthly goals, are we meeting our expectations to FHWA and are we meeting our expectations to the districts. I think short-term goals are a good thing when you are starting a new program to kind of take steps and not just have inapplicable goals"* (L3 employee). Some participants stated that short-term goals are important but cannot replace long-term goals, especially if they are trying to show the long-term savings or wins behind implementing a new program: *"Short-term goals are fine as long as everybody knows what the long-term goal is. If you tell me to change and I don't know why I will be resistant to that" (L3 employee).*

6. DISCUSSION

6.1 Research Question 1

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. During our analysis of the literature, we found that many researchers were against the 24-month inspection interval (Nasrollahi & Washer, 2015; Soliman et al., 2013; Washer et al., 2016a). For example, Washer et al. (2016a) 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, Nasrollahi and Washer (2015) concluded that the fixed inspection cycle can lead to unnecessary inspections for many bridges in the national bridge inventory.

While some of the participants agreed with what was found in the literature, surprisingly, most participants supported the 24-month inspection cycle over a variable inspection cycle. Supporters of the fixed inspection interval said it is a simple and clear approach for scheduling inspections and helps manage resources and prepare inspection budgets, especially for large networks; they added it is conservative and safe, helps monitor and keep up with bridge deterioration, and helps group bridges geographically to save traveling time and cost. From what is available in the literature, it is clear 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 would 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 (Frangopol & Bocchini, 2012; Yang & Frangopol, 2018b; Zhang & Wang, 2017). This provides a small sample of the differences between researchers and practitioners in the bridge inspection field.

Although most of our participants supported the 24-month inspection cycle, an L2 manager mentioned that the FHWA was pressured by DOTs to allow an alternative for scheduling inspections, such as the risk-based approach (Washer et al., 2014), so that DOTs can save some resources spent unnecessarily on bridge inspections, indicating there is disagreement among practitioners. This variety of opinions was evident in the participants' comments about the risk-based approach, which the FWHA is considering to allow as a second alternative for scheduling routine inspections (FHWA, 2019). Some participants found that this approach will help reduce the number of inspections and save resources, while others were concerned about the time and effort that would be required to set the risk-based inspection panel, update the bridge management system, and collect the data required to set the inspection intervals.

With regard to the methods used during inspections, participants agreed with what was found in the literature and the NBIS (FHWA, 2012), 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 (Hearn, 2007). Regardless of the limitations and variability of visual inspections proved several times in the literature (Bu et al., 2014; Lin, Pan, Wang, & Li, 2019; Pines & Aktan, 2002), participants used visual inspections to rate bridge conditions, decided on whether the inspection cycle needed to be reduced or not, and even planned for maintenance work.

Due to the limitations of visual inspections, many scholars suggested the use of other NDE methods (Alampalli & Jalinoos, 2009; Vaghefi et al., 2012). In our investigation, we found that most participants used 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 & Kalos (2015). Further, according to a survey conducted by Lee and Kalos (2015), the main barriers hindering the use of NDE methods in

state governments is the capital cost needed to purchase the equipment and the difficulty associated with some NDE techniques. Adding to what Lee and Kalos (2015) concluded, participants in our study mentioned that although NDE methods have a potential to improve inspections, they require training and certifying inspectors, which is a huge burden on bridge inspection divisions. Also, some NDE methods require time to set up in the field, traffic control, and access to equipment such as snoopers.
In connection with our main study objective to improve inspections, we discussed with participants the main aspects that can help improve inspection data. Many participants mentioned that training bridge inspectors and enhancing their abilities can lead to significant improvements in the value of bridge inspections. Lin et al. (2019) 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, some participants stated that developing clear policies and protocols for bridge inspections can help reduce ambiguity and differences between DOTs, which agrees with what Phares et al. (2004) found during their study on the reliability of bridge inspections. Also, one participant suggested the relatively interesting idea of adjusting inspection efforts depending on the condition of the bridge to reduce inspection effort and time.

6.2 Research Question 2

Based on our discussion with participants on the different inspection planning approaches and NDE techniques, several participants pointed out that researchers need to provide practical and clear research results that can be readily understood and applied in practice. 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 some participants recommended. Azhar, Ahmad, and Sein (2010) found that some of the main reasons hindering implementation of research findings in the construction industry is that researchers focus on theoretical or conceptual issues that are impractical or inapplicable; on the other hand, practitioners do not accept new research ideas that can require change in their daily procedures or industrial traditions. Bahadori, Raadabadi, Ravangard, and Mahaki (2016) stated that time constraints can make it difficult for practitioners to read and refresh their knowledge with new research or evidence that can be applied in the field. Moreover, participants noted that researchers should not only focus on solving specific problems or providing frameworks and ideas that can only be applied on specific types of bridges or deteriorations.. Researchers need to provide practical solutions that can be applied on different bridge types and scenarios, not just limited bridge cases. This will help justify the costs of research implementation.

In this context, to provide effective research products, participants suggested working together and collaborating as researchers and practitioners to improve research products and direct researchers' effort in the right direction. Researchers in the implementation field found that collaboration between academics and practitioners in the industry can significantly improve research results and expedite research and knowledge transfer into practice (Brannick & Coghlan, 2006; Cheng & Kong, 2009). Also, focusing on problems and research ideas that are important to DOTs, such as using drones or improving NDE data, can help the implementation process. After studying several case studies in the construction industry, Azhar et al. (2010) concluded that using active research techniques can enhance collaboration between researchers and practitioners and help solve some of the important problems practitioners are facing. 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 (Avison, Lau, Myers, & Nielsen, 1999). This approach can be applied in DOTs, not just to improve research products and collaboration in the field, but to save time and scarce resources.

In addition, researchers in the bridge inspection field can promote their research findings by providing practitioners with summaries and synopses of key findings to update them and save their time. These synopses 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) (Barbour, 2007).

Conferences such as the Transportation Research Board (TRB) can also help gather academics and workers in the industry to discuss and address important issues in the industry, and even share successful implementation strategies (Harder, 2014).

To improve research products further and make sure that research findings are applicable, researchers in the bridge inspection field can use ideas like Technology Readiness Scales (Laughlin et al., 2007) or product evaluation criteria developed by NCHRP (Dekelbab et al., 2017). 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 on different cases before deploying it. DOTs can even hire a single staff member or a research and development team responsible for finding innovative solutions and evaluating their applicability.

6.3 Research Question 3

Members of the bridge inspection divisions provided valuable information on some of the factors that can potentially contribute toward a successful organizational change in DOTs and facilitate research implementation. Some of these factors are in close correspondence with 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 technology or planning framework in the bridge inspection divisions. Kotter (1995) 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 (Armenakis, Harris, & Feild, 2000; Judson, 1991). 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 of change and create a strategy to reach the required outcomes (Kotter, 1995).

Based on several case studies in U.S. local governments, Denhardt and Denhardt (1999) 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 their problems to program managers during inspections and try to create actions that can help improve the inspection process. Moreover, if researchers have a strong understanding of 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 in 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 (CDOT, 2021). 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 (CDOT, 2021) .

Change in DOTs mainly starts with the FHWA as we saw in the risk-based inspection framework. However, participants mentioned that one of the main barriers of change is convincing the FHWA about the importance of this change and its benefits. The organizational change literature related to public organizations contains evidence that change leaders need to justify to external stakeholders regarding the need for change, especially if these stakeholders have the ability to provide necessary resources and should authorize the change before it even starts (Abramson & Lawrence, 2001). On the other hand, the FHWA can help stimulate change and promote urgency among DOTs by mandating changes they see as necessary or showing dissatisfaction toward a DOT's performance that requires immediate change. As shown in the results, one of the DOTs initiated change and developed a centralized inspection team to improve inspection data after being warned by the FHWA. Van de Ven (1993) 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 at different occasions. Gaining support from the FHWA during change can help push the change forward and institutionalize change among DOTs. From our study, we recognized that the FWHA can support DOTs during change by: 1) providing guidance and administrative and technical help during the change process; 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) ensure that change goals are clear to remove ambiguity and differences among DOTs; 4) acknowledge 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 DOT capabilities; 5) help DOTs find the required financial resources during change; 6) provide inspectors and DOT staff members with training that can help prepare them for change and reduce variation among bridge inspectors; and 7) develop 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 (Rosenbaum et al., 2017). Participants found that one of the main reasons for a successful change in their department was the commitment and quality of the staff members. As a part of creating readiness for change, Armenakis et al. (2000) stated that leaders need to motivate staff members and show them that they have the ability to succeed in this change. Also, communicating with staff members and allowing them to participate is prudent for the transition process (Abramson & Lawrence, 2001; Bunker & Alban, 1997; Judson, 1991; Kanter, 1983). In our investigation, communication among different levels of staff members was mentioned several times as a key component for a successful transition process. During a change, communication can help reduce uncertainty and ambiguity (Allen, Jimmieson, Bordia, & Irmer, 2007; Bordia et al., 2004), which were problems some participants experienced during organizational changes in their departments. It is also 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 (Kotter, 1995).

Participants also mentioned that applying a new inspection planning framework or adapting new tools during inspections, such as NDE methods, updating the bridge management system, or automating inspection reports, 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 confidently implement a new technology and also measure its applicability (Dekelbab et al., 2017). Training can help staff members see change as an opportunity for growth and advancement in their career, especially if they were rewarded with promotions or certificates after attending the training (Bartlett & Kang, 2004).

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. Harder (2014) 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 (Desouza et al., 2009). In some cases, transportation agencies can reach out to external expertise and even hire part-time workers to carry out the primary duties of the organization until the in-house staff members adapt to the new change process. Moreover, participants found that one of the main problems to apply 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 (Fernandez & Rainey, 2006). Several participants mentioned that one of the main barriers to implementing a new idea is the limited budgets most DOTs currently have. Boyne (2003) found that sufficient funding is one of the important factors to improve public organizations and promote innovation. During change, funding will be required to train and prepare staff, purchase the required equipment, promote and communicate the new idea among practitioners in the field, and restructure the organization (Nadler & Nadler, 1998). Harder (2014) acknowledges that one of the main reasons hindering the rate of innovation adoption in the highway industry is not having a systematic perspective for research implementation that can help develop sustainable funding sources for research. Most change leaders or 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 (Dekelbab et al., 2017).

One common factor was found among all the change driving aspects mentioned by participants: having 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. The literature is full of evidence on the importance of leadership and top management support during change (Abramson & Lawrence, 2001; Armenakis & Harris, 2009; Fernandez & Rainey, 2006; Kotter, 1995; Luecke, 2003; Nadler & Nadler, 1998). Change leaders can be a single individual (Kanter et al., 1992) or a group of staff members able to guide the change process (Kotter, 1995; Yukl, 2008). 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 bridge inspection divisions might find these propositions as common sense; however, studies have found that managers sometimes ignore or underestimate some of these factors (Fernandez & Rainey, 2006). Also, our focus was mainly on bridge inspections and DOT departments, but one may infer that these factors can help other transportation agencies and government organizations in applying change and implementing new research findings.

7. CONCLUSIONS & RECOMMENDATIONS

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. This study used semi-structured interviews, written interviews, and questionnaires for data collection to provide rich and accurate results. Twenty-six staff members from different DOTs with different managerial levels and responsibilities were involved in this study. A thematic analysis process was used to analyze the data collected; and based on the participants responses, we reached the following conclusions and recommendations:

1- Many researchers in the field of bridge inspection planning do not support the 24-month inspection cycle used to schedule routine inspections. However, 44% of the participants in our study supported this fixed-time approach, 24% were against it, and the others were in the middle and stated that it has both benefits and drawbacks. The participants who supported the 24-month inspection cycle stated that it is a safe and simple approach that helps in planning and budgeting inspections. It was also suggested that having a variable inspection schedule will require increasing or downsizing bridge inspection crews, which is a hard task in government organizations. On the other hand, participants who were against the fixed approach found that it wastes resources and does not consider the bridge condition or in-service environment.

2- For the risk-based approach provided by NCHRP as an alternative for scheduling inspections, 36% of the participants said they will apply it once it is allowed, 21% said they will not consider it, and 43% indicated they will wait and see how other state departments will apply it. Some participants found that this alternative scheduling process will help them reduce the number of inspections and free resources. Others were concerned about the time and effort needed to assemble the expert panel and the data that will be required to establish the inspection intervals.

3- During our investigation of current inspection practices, we found that participants mainly use NDE methods during in-depth inspections, and the reasons limiting its use are the training and certifications required by bridge inspectors, cost of equipment, time to assemble on site, and the need for the traffic control and mobility equipment such as snoopers and man lifts.

4- Participants suggested that focusing on training inspectors and developing clear protocols for inspections can help improve the quality of inspections. They also recommended that researchers should focus on enhancing the data collected from NDE methods and drones, developing frameworks to implement these data in the decision-making process, helping practitioners in the inspection field predict the life cycle of bridges constructed using new materials and technologies, and providing new methods that can help link the element level inspection data with the NBI rating system.

5- Participants mentioned that, in many cases, research results in the bridge inspection field are not clear and concise and can only be applied on special bridge cases or deteriorations. As a result, some participants recommended collaboration between researchers and practitioners to improve the relevancy and effectiveness of research products to encourage its utilization.

6- Based on our analysis, we recommend using techniques such as action research methods that can enhance collaboration between researchers and practitioners and enhance innovation in the bridge inspection field. Also, researchers and sponsors could develop platforms that publish summaries and systematic reviews of important research results, which DOT managers and decision makers can easily navigate and understand. Hiring a single staff member or forming a team of experts in the DOT, who have the time to review new research findings and evaluate their applicability, can also facilitate research transfer.

7- From our discussion with participants, we concluded that the main factors that can help facilitate change in DOT bridge divisions are showing the need for change, gaining support from the FHWA, allocating the required funding and workforce, and enhancing the capacity of DOT staff inspectors through training and effective communication. However, these efforts will not be effective if they were not supported by committed leaders and program managers.

This study provides DOTs and researchers with practical and theoretical solutions to help accelerate change and research transfer. However, it should be noted that participants were not experts in organizational change theories and research implementation; thus, the factors recommended in this study are not the only ones that can help facilitate change, and other factors can be found in the literature or when including other stakeholders. Future research should focus on including other external stakeholders such as FHWA staff members and consultants working in bridge inspections. This study focused on DOTs in the United States; however, including transportation agencies from other countries will provide a broader picture and can even yield different results. Researchers need to also focus on helping transportation agencies develop a sustainable and reliable source of funding that is dedicated to research and development. Also, during our investigation, it was found that phone or video interviews provided richer answers than written interviews even though the number of participants in the written interviews was higher. This point should be noted by future researchers who will build their studies on interviews.

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APPENDIX (A): BRIDGE INSPECTION QUESTIONNAIRES

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- Non-destructive testing (NDT) methods)
3) From your experience what actions can be done 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 done 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): SUMMARY OF THE JOURNAL ARTICLES THAT WERE SENT TO PARTICIPANTS

The first article was published by Washer et al. (2016a) and presented an inspection planning framework that was proposed by the National Cooperative Highway Research Board (NCHRP) in the NCHRP Report 782 based on the NCHRP 12-82 study (Washer et al., 2014). The framework is based on risk analysis where the consequences and likelihood for a certain damage mode to affect the safety and serviceability of a bridge is quantified using simple quantitative tools and expert judgment. Based on the condition of the bridge and the consequences of the failure, the bridge is ranked and the appropriate inspection interval is decided. To implement this program, a reliability assessment panel is assembled consisting of a group of experts in the field of bridge inspection. These experts are required to decide on the attributes that contribute to the analyzed damage mode and decide on the likelihood and consequences of failure. This study was chosen to be sent to the participants, because it is simple and is based mainly on expert judgment and does not require a great deal of training or sophistication.

The second article discusses an inspection planning framework proposed by Kim and Frangopol (2011). The framework uses optimization algorithms and decision trees to choose the optimum inspection time and method that will minimize maintenance delay and inspection cost. Prediction models were used to predict the time of corrosion initiation while considering the uncertainty in the deterioration process. The probability of detection was used to describe the quality of the inspection method (NDE method) and compare between the different methods. The method with higher probability of detecting a crack is more preferred than another method with a probability of detection. This framework will require a bridge inspection planner able to verify the quality of a prediction model, use optimization algorithms, and have the required knowledge in probability and statistics. The reason for choosing this study is that it represents a significantly different approach for inspection planning compared with the study proposed by Washer et al. (2016a), and will require high computational tools and skills to apply.

The third article focuses on using the probability of detection in choosing the appropriate inspection interval for different NDE tools. The study was proposed by (Chung et al., 2006) and focused on inspection planning for steel bridges. The objective of the planning framework is to choose the optimum inspection interval that will maximize the probability of detection while reducing the total cost of inspection. The inspection cost included the cost of inspection and bridge failure. Three NDE methods were compared: ultraviolet inspection, liquid penetrant inspection, and magnetic particle. The study found that inspection methods with higher quality will allow longer inspection intervals compared with lower quality methods. This study requires knowledge of probability and statistics and some computational effort, but it is not as complex as the framework proposed by Kim and Frangopol (2011); yet, it is also not really simple or depends solely on expert judgment like the study presented by Washer et al. (2016a).

APPENDIX (C): JOURNAL ARTICLES INTERVIEWS

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-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, will 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: question 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 for 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 inspection (2 years) be changed or be 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 (D): 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 implementations 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 be those short-term goals?
   h) From an organization 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 (E): 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 done 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 questions 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 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 organization 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.

Q18) 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.