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Advancing the understanding of successful technology implementation factors within state DOTs: a maturity model perspective

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In an effort to improve the security, dependability, and quality of infrastructure systems, the implementation of complex transportation construction and maintenance projects is essential. Building upon a previous study that identified six crucial factors for effectively implementing new and emerging technologies in the State Department of Transportations (DOTs), this research aims to comprehensively explore six critical factors using a maturity model perspective. DOTs have shown increasing interest in adopting emerging and wireless technologies, as evident in various Federal Highway Administration Every Day Counts initiative. This study employs a mixed-methods approach, using survey responses from DOT personnel to evaluate the relative significance of technology implementation factors and subfactors. The six factors for successful technology implementation explored in this study are Organization Structure, Information Technology Infrastructure, Data Security, Information Workflow, Personnel Training, and Stakeholder Engagement. The study also evaluates the relative importance of People, Process, and Technology for each of these six factors. The paper focuses on providing detailed insights into the different criteria of each technology implementation factor and subfactor to guide agencies in successful technology deployment. Understanding these factors is critical to deploying emerging technologies successfully, which, in turn, leads to much-needed efficiency and productivity in highway construction and asset management. The findings of this study can help DOTs prioritize their technology investments and ultimately contribute to the development of a more advanced and sustainable transportation infrastructure system.

KEYWORDS

technology implementation, maturity models, emerging technologies, implementation factors, people process technology (PPT) model

1 Introduction

The implementation of emerging technologies in state Departments of Transportation (DOTs) is becoming increasingly important in ensuring the safety, reliability, and efficiency of transportation infrastructure systems. Emerging technologies are defined as technologies that are radically novel, fast-growing in use, and comprehensible and that demonstrate prominent impact as well as uncertainty (Rotolo et al., 2015). Across the country, DOTs are facing the challenge of doing more with fewer resources and managing more complex projects. Additionally, it is well known that the construction industry has not seen productivity growth compared to other industries. To advance construction, organizations are leveraging existing studies that have shown a positive correlation between productivity growth and the extent to which the industry is digitalized (Pistorius, 2017). Therefore, to increase the much-needed productivity and efficiency in the highway construction and infrastructure asset management, the Federal Highway Administration (FHWA) has launched many initiatives and efforts. One such initiative is Every Day Counts (EDC) initiative. EDC is a state-based model that identifies and rapidly deploys proven yet underutilized innovations that make the transportation system adaptable, sustainable, equitable, and safer for all. Through the EDC model, FHWA works with state and local transportation agencies and industry stakeholders to identify a new collection of innovations to champion every 2 years. The EDC program has made a significant positive impact in accelerating the deployment of innovations and in building a culture of innovation within the transportation community (Center for Accelerating Innovation, 2023). However, successfully implementing these technologies requires careful planning and execution, and implementation success is not always guaranteed. This has led to a growing interest in identifying critical factors for successful technology implementation in state DOTs.

The purpose of this paper is to provide a holistic overview of technology implementation within state DOTs based on the exploration of six critical factors for successful technology implementation. The selection of the six factors was identified by collaborative efforts of a diverse group of project panels involved in the NCHRP 03-140 project. These panels, represent various state DOTs including Maryland DOT, Maine DOT, Texas DOT, Michigan DOT, North Carolina DOT, as well as academic institutions such as Oregon State University, and key stakeholders like FHWA and the American Association of State Highway and Transportation Officials (AASHTO), collectively identified these factors as crucial for technology implementation. These six key technology implementation factors were identified as critical and indispensable considerations for technology implementation. These factors, as identified and outlined in (Dadi et al., 2023a) include Organization Structure, Information Technology (IT) Infrastructure, Data Security, Information Workflow, Personnel Training, and Stakeholder Engagement (Dadi et al., 2023a). The research team was not permitted to include any additional factors during the research. In addition to these six factors explored here, there are other potential factors that could influence successful technology implementation: Resource Allocation, Change Management, Risk Management, Vendor and Supplier Relationship. An organization's adept management of resource allocation to ensure sufficient budget, time, and manpower, coupled with effective change and risk management practices, nurturing strong vendor relationships, and fostering alignment with organizational culture and objectives, collectively underpin the successful implementation of technology initiatives, optimizing outcomes and minimizing disruptions. The study also explores important subfactors within these six implementation factors and determines the relative importance of People, Process, and Technology for each factor. In addition to identifying critical factors for successful technology implementation, this paper also utilizes a maturity model to define different maturity levels of subfactors. The maturity model provides a framework for assessing the current implementation state, identifying improvement areas, and tracking progress over time. The scalability of the framework allowed for the inclusion of additional factors and emerging technologies as needed, ensuring adaptability to evolving challenges. By incorporating this approach, this study not only identifies critical factors for successful implementation but also provides a means for state DOTs to measure their maturity and advance their technology implementation practices. This approach can assist state DOTs in developing a strategic roadmap for implementing emerging technologies, leading to improved efficiency and quality of infrastructure. The significance of this study lies in its potential to help state DOTs or any other organizations focus on important factors required for successful technology implementation, which can lead to improved efficiency, reduced costs, enhanced infrastructure quality, and more success stories. This paper presents the findings of the recently completed research project that aims to investigate the critical factors and criteria for successful technology implementation in state DOTs.

The scope of this study is limited to state DOTs in the United States, and the limitations of this study include the reliance on existing literature and data sources and the potential for subjective interpretation of the research findings.

2 Literature review

The construction industry can benefit greatly from the use of new and emerging technologies. To deliver critical and intricate highway projects throughout the United States, state DOTs rely on innovative and cutting-edge technologies. Various emerging technologies are used in highway construction and asset management (Bou et al., 2023). These include visualization and modeling technologies such as building information modeling, virtual and augmented reality, Light Detection and Ranging (LiDAR), and 3-D printing. Interconnected technologies for construction vehicles, equipment, and tools are used for delivery and haul vehicles, pavement and earthwork equipment, and handheld tools. Advanced safety technologies such as work zone intrusion alarms, proximity warning systems, enhanced personal protection equipment, Dynamic Message Signs (DMSs), and Variable Speed Limit (VSL) zones are also used. Additionally, instrumentation and sensor technologies include Real Time Kinematic (RTK) handheld Global Positioning System (GPS) devices, remote sensing, and devices that measure specifications, structural integrity, and environmental conditions. Lastly, Unmanned Aircraft Systems (UAS) technologies perform construction surveying, site mapping and inspections, and monitoring work progress (Christofer Harper Daniel Tran and Ed Jaselskis, 2019). Visualization and modeling technologies are predominantly utilized to conduct constructability reviews, as-built documentation, quality control and quality assurance, and simulating bridge and non-bridge construction. Machine control systems and vehicle tracking are interconnected technologies that are primarily used for earthwork and paving equipment. Safety technologies play a significant role in construction by managing work zone traffic, providing real-time information, and preventing accidents. Progress monitoring, quality control and quality assurance, and construction inspections are all instrumentation and sensing technologies applications. Unmanned aircraft systems are used to monitor progress, map sites, survey, and document construction work (Christofer Harper Daniel Tran and Ed Jaselskis, 2019).

Integrating two or more technologies can improve effectiveness in design and construction processes. The results of EDC-2 showed that combining three-dimensional (3D) modeling and GPS for machine control and guidance resulted in completing construction surveys faster and with improved safety and quality. It can increase productivity by up to 50% and cut survey costs by up to 75% (EDC-2, 2023). One of the emerging technologies promoted by EDC-3 e-construction can save 1.78 h per day per inspector, and inspectors collect 2.5 times more data than conventional methods (Weisner and Cawley, 2017).

As the construction industry has displayed little productivity growth during the past two decades (McKinsey Global Institute, 2017), the use and adoption of effective practices to infuse new technologies, new materials, and advanced automation can increase productivity by 6%–10% and result in cost savings of 4%–5% (Christofer Harper Daniel Tran and Ed Jaselskis, 2019). Implementation of automation on construction sites is a mechanism to enhance construction productivity (McKinsey Global Institute, 2017). To realize all the benefits and improvements technologies can bring to state DOTs, it is highly important to understand and explore critical factors related to technology implementation. Technology implementation requires a holistic approach focused not only on technology but also on other factors. Any attempt to implement technology focusing solely on the technological aspect is likely to fail in the construction industry (Love et al., 2022). Less than 10% of technology implementation failures are due to technical problems, and more than 80% to 90% of implementation failures are due to human- and organizational-related issues (Griffith, 1996). Other research states that 80% success of new technology implementation depends on addressing personnel and process issues, and only 20% is related to addressing technical aspects (Bilge et al., 2014; Lines et al., 2016). The failure rate of technology implementation due to people- and process-related issues suggests that technology implementation should not be solely focused on technology, but rather, it should consider all three aspects: People, Process, and Technology. A study conducted by (Lines et al., 2016) investigated the role and importance of People, Process, and Technology for successful technology implementation within state DOTs and found that state DOTs seeking successful technology implementation should achieve at least a maturity level of 3 for People, Process, and Technology. The same study found that when the maturity level for People, Process, and Technology is at or below 2 results in unsuccessful technology implementation (Tripathi et al., 2023a). The authors focused the paper on the People, Process, and Technology (PPT) maturity framework. The PPT framework maps the entire value stream of people, processes, and technology and highlights their interaction.

In line with previous research efforts (Secrest et al., 2011; Arlington, 2022) that focused on highway construction and made modifications to widely used maturity models, the authors adapted the People Capability Maturity Model (PCMM), Project Management Maturity Model (PM)^2, and Capability Maturity Model Integration (CMMI) to assess the maturity of People, Process, and Technology, respectively, in the context of state departments of transportation (DOTs) (Tripathi et al., 2023a; Tripathi et al., 2023b). Understanding the distinction and significance of readiness and maturity concepts is crucial for the successful implementation of technology in state DOTs (Tripathi et al., 2022). Successful technology implementation depends on the maturity of both state DOTs and the technology itself. Mature state DOTs have achieved a level of maturity in terms of People, Process, and Technology within their organization, while mature technology has undergone extensive testing and possess well-defined functionalities (Secrest et al., 2011). There are numerous examples where state DOTs exhibit maturity in their operations while the technology being implemented lacks maturity, or *vice versa*, leading to unsuccessful technology implementation. These scenarios emphasize the importance of aligning the people and processes of state DOTs and the maturity levels of the technology being implemented to achieve positive outcomes. It is necessary for state DOTs to recognize and address any discrepancies between the maturity levels of their organizational capabilities (people and process) and the technologies they seek to implement to ensure successful outcomes in technology implementation endeavors.

This project is an extension of the findings of a project funded by the National Cooperative Highway Research Program (NCHRP 03-140), where the researchers, along with a panel of technology implementation subject matter experts, identified the following six technology implementation factors as critical and must be considered when implementing a technology: Organization Structure, Data Security, IT Infrastructure, Information Workflow, and Personnel Training, and Stakeholder Engagement (Dadi et al., 2023a; Dadi et al., 2023b; Hatoum et al., 2023). Using the identified six factors, the authors of this paper, in their previous study, found the overall ranking of the six implementation factors based on the survey of DOTs personnel. The overall ranking of the six factors on the basis of importance is as follows: Stakeholder Engagement, IT Infrastructure, Information Workflow, Organization Structure, Personnel Training, and Data Security, as shown in Table 1. Rank 1 indicates the highest ranking assigned to a particular factor, followed by Rank 2, and so on, with Rank 6 being the lowest ranking. The numbers in Table 1 represent the count of responses for each ranking category, with higher numbers indicating greater respondent agreement on the importance of a particular factor. This ranking of six technology implementation factors stayed unchanged when these six factors ranking were validated with a different group of state DOT experts (Tripathi et al., 2023a). While the average ranking of six factors stayed the same, it is important to note that the ranking may vary from one state DOT to another based on the agency requirements.

The six implementation factors identified in the previous work (Lines et al., 2016) and explored in this study can be broadly classified into two categories: data and technology governance and change management (Sharma et al., 2009). Data and Technology Governance factors, including IT Infrastructure, Data Security, and Information Workflow, primarily focus on the effective management, protection, and utilization of data and technology. These factors serve as the foundation for successful technology implementation and can significantly impact the overall performance of the technology solution. On the other hand, Change Management factors, namely, Organization Structure, Personnel Training, and Stakeholder Engagement, concentrate on the human aspects of technology implementation. These factors are crucial in ensuring the successful adoption and acceptance of new technologies by end-users, stakeholders, and the organization. The following paragraph briefly explains these implementation factors. Considering and addressing these implementation factors collectively contribute to successfully integrating new technologies in the construction industry. By prioritizing IT infrastructure, data security, information workflows, stakeholder engagement, organization structure, and personnel training, organizations can enhance the overall effectiveness and efficiency of technology implementation, leading to improved project outcomes and increased competitiveness in the industry.

TABLE 1 Number of Responses for Ranking of Six Technology Implementation Factors (Adapted from Tripathi et al., 2023).

Factors	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Rank 6
Organization Structures	11	9	17	7	7	23
IT Infrastructure	17	15	11	14	11	6
Data Security	6	7	12	13	13	23
Information Workflows	3	14	14	24	15	4
Personnel Training	0	13	13	12	24	12
Stakeholder Engagement	37	16	7	4	4	6

- IT Infrastructure is a key implementation factor that plays a crucial role in supporting the successful implementation of new technologies. It encompasses a range of robust and scalable components, including servers, networking equipment, storage systems, software platforms, and other hardware elements. These components form the underlying technological foundation necessary to facilitate the seamless deployment of technology solutions within the organization. An effective IT infrastructure is essential for ensuring the efficient operation of new technologies, enabling them to handle and process large volumes of generated data and providing secure access to end-users (Al-Sabaawi, 2015; Janssen, 2015; Merhi, 2023). Some of the subfactors for IT Infrastructure are:

o Hardware Capabilities (Aldowah et al., 2019): This subfactor refers to the capabilities of hardware used for technology implementation. It is important because it ensures that the hardware is capable of supporting the technology solutions being implemented.

o Software Capabilities (Aldowah et al., 2019) This subfactor refers to the capabilities of software used for technology implementation. It is important because it ensures that the software is capable of supporting the technology solutions being implemented.

o Data Storage (Nyikes and Rajnai, 2015; Cheblakov et al., 2017; IBM, 2022) This subfactor refers to the storage and management of data used in technology implementation. It is important because it ensures that the data is stored securely and is easily accessible by stakeholders. This subfactor refers to the ability of the technology solutions to support mobile devices such as smartphones and tablets. It is important because it ensures stakeholders can access and use the technology solutions anywhere.

o Mobility (CHG, 2022; Honekamp; Blog, 2023): This subfactor refers to the ability of the technology solutions to support mobile devices such as smartphones and tablets. It is important because it ensures stakeholders can access and use the technology solutions anywhere.

o Interoperability (Sherman, 2022; ADSC, 2023; DOT, 2023) This subfactor refers to the ability of the technology solutions to work with other systems and software. It is important because it ensures that the technology solutions can be integrated with existing systems and can exchange data with other systems.

o Scalability (Milat et al., 2013; BLOG, 2023): This subfactor refers to the ability of the technology solutions to accommodate growth and expansion in the future. It is important because it ensures that the technology solutions can support the organization's growth and changing needs over time.

- Data Security is another critical factor that requires careful consideration during technology implementation. It focuses on safeguarding sensitive data from unauthorized access, breaches, and cyber-attacks. Organizations must implement robust access controls, encryption mechanisms, and other security protocols to achieve data security. These measures protect data at rest and in transit, ensuring its confidentiality, integrity, and availability. Developing a comprehensive data security plan as part of the technology implementation project is essential. Regular reviews and updates of this plan help address emerging threats and vulnerabilities, keeping the organization's data assets secure (Ervural and Ervural, 2018; Merhi, 2021; Merhi, 2023). Some of the subfactors of Data Security are:

o Data Collaboration and Accessibility (Sukumar and Ferrell, 2013; Kulkarni, 2019; CIO, 2023): This subfactor refers to the level of collaboration and accessibility of data between stakeholders during technology implementation. It is important because it promotes collaboration, knowledge sharing, and informed decision-making.

o Data Security policies (Aaron and Hugh, 2013; Velumadhava Rao and Selvamani, 2015; Saa et al., 2017): This subfactor refers to the policies and procedures in place to protect data from unauthorized access, use, disclosure, or modification. It is important because it ensures that sensitive and confidential data is protected from potential threats and breaches.

o Data Management (Kaufmann, 2019; Data Management Trends and Technology, 2021; Tableau, 2023) This subfactor refers to the management of data throughout its lifecycle, including data creation, capture, storage, retrieval, and disposal. It is important because it ensures that data is accurate, reliable, and available when needed.

o User Authentication and Access Control (Roy, 2018; Ali et al., 2019; Cyber Security, 2022) This subfactor refers to the measures in place to authenticate users and control their access to data and systems. It is important because it ensures that only authorized users have access to sensitive data and systems and helps prevent unauthorized access and security breaches.

o Data Backup and Recovery Mechanisms (Backup and Recovery of Data, 2022; EMBEE, 2023) This subfactor refers to the measures in place to backup and recover data in case of system failures, disasters, or security breaches. It is important because it ensures that data can be restored in case of data loss or system failures and helps prevent downtime and disruptions.

o Risk Assessment and Compliance (Humphreys, 2008; Racz et al., 2010): This subfactor refers to the identification, assessment, and management of risks associated with technology implementation, as well as compliance with relevant laws, regulations, and standards. It is important because it ensures that the organization is aware of and able to manage potential risks associated with technology implementation and complies with relevant laws and regulations.

- Information Workflow is a vital aspect of technology implementation that aims to optimize the flow of information within the organization. Designing effective information workflows ensures efficient data collection, processing, and sharing processes. Organizations can streamline operations and enhance decision-making capabilities by minimizing redundancies and avoiding bottlenecks. It is crucial to capture data accurately and in a timely manner, enabling easy accessibility for those who require it. Well-designed information workflows contribute to improved coordination, collaboration, and knowledge management within the organization (Channgam et al., 2019; zur Muehlen, 2004; Sankaran et al., 2018). Some of the subfactors of Information Workflow are:

o Data Collection (Adams, 2008): This subfactor refers to the process of collecting data for use in technology solutions. It is important because it ensures that the data collected is relevant, accurate, and reliable.

o Data Processing (Chen et al., 2012; U.S. Department of Transportation Roadway Transportation Data Business Plan Phase 3, 2021) This subfactor refers to the process of processing and analyzing data for use in technology solutions. It is important because it enables stakeholders to make informed decisions based on accurate and relevant data.

o Data Validation (What is Data Validation?, 2021; Rizk et al., 2019): This subfactor refers to the process of validating the accuracy and completeness of data used in technology solutions. It is important because it ensures that the data used in technology solutions are accurate, reliable, and valid.

o Data Integration (What is Data Validation?, 2021; Rizk et al., 2019): This subfactor refers to the integration of data from different sources and systems for use in technology solutions. It is important because it enables stakeholders to access and use data from different sources and facilitates informed decision-making.

o Data Reporting and Visualization (Revolutionize Business Insights with Analytical Reporting Tools - Ad Hoc Reporting, 2007; Frank et al., 2015): This subfactor refers to the presentation of data in a way that is easily understandable and actionable for stakeholders. It is important because it enables stakeholders to make informed decisions based on data insights.

o Workflow Optimization (Reiner et al., 2002; Quandarycg, 2010; Kougka et al., 2018): This subfactor refers to the optimization of processes and workflows through technology solutions. It is important because it enables stakeholders to improve efficiency, reduce costs, and enhance quality in their work processes.

- Stakeholder Engagement is a pivotal factor that involves active collaboration with various stakeholders throughout the technology implementation process. Engaging stakeholders, including end-users, vendors, contractors, and regulatory agencies, is essential for ensuring the successful adoption and deployment of new technologies. Effective stakeholder engagement entails identifying and addressing their concerns and needs, creating a shared vision for the technology implementation project, and establishing clear communication channels. By actively involving stakeholders, organizations can foster a sense of ownership, commitment, and support, which are crucial for the successful integration of technologies (Chinyio and Olomolaiye, 2010; Boet et al., 2021; Shah and Guild, 2022). Some of the subfactors of Stakeholder Engagement are:

o External Stakeholder Coordination (Brem et al., 2011; Teo et al., 2017; Lehtinen and Aaltonen, 2020): This subfactor refers to the extent to which the organization coordinates with external stakeholders such as customers, partners, vendors, and regulatory agencies during technology implementation. It is important because it ensures that external stakeholders are involved in the implementation process, which can lead to a better alignment of technology solutions with their needs and requirements.

o Internal Stakeholder Coordination (Brem et al., 2011; Teo et al., 2017): This subfactor refers to the extent to which the organization coordinates with internal stakeholders such as employees, managers, and departments during technology implementation. It is important because it ensures that internal stakeholders are aligned with the implementation process, which can lead to better adoption and utilization of the technology.

o Stakeholder Readiness (Nicolai et al., 2022; Seko et al., 2022): This subfactor refers to the level of preparedness of stakeholders for the technology implementation. It is important because it ensures stakeholders have the necessary knowledge, skills, and resources to use the technology effectively.

o Communication and Transparency (Smith, 2017; Implementing Education Policies, 2019): This subfactor refers to the quality and frequency of communication between the organization and stakeholders during technology implementation. It is important because it promotes transparency and accountability, builds trust, and ensures that stakeholders are informed and engaged throughout the implementation process.

o Stakeholder Involvement and Participation (Strecker et al., 2011; Luyet et al., 2012; Leopizzi, 2020): This subfactor refers to the level of involvement and participation of stakeholders in the technology implementation process. It is important because it ensures that stakeholders are empowered and have a voice in shaping the technology solutions that are being implemented.

- Organization Structure plays a significant role in technology implementation projects. It involves establishing a clear and well-defined structure that outlines the roles, responsibilities, and relationships of team members involved in the implementation process. The organizational structure also establishes reporting lines, decision-making processes, and coordination mechanisms. A well-structured organization provides a framework for effective project management, ensuring that all team members are aligned and working towards common project goals. It facilitates efficient communication, resource allocation, and collaboration, enabling the smooth execution of technology implementation initiatives (Baker and Baker, 2012; Dahlan et al., 2021). Some of the subfactors of Organization Structure are:

o Organizational Vision and Objectives (Halaweh and Massry, 2015; Tetef, 2017): This subfactor refers to the extent to which the organization has a clear vision and objectives for technology implementation. It is important because it directs the implementation process and helps ensure the technology solutions align with the organization's strategic goals.

o Management Support (Young and Jordan, 2008; Shaar et al., 2015; Garcia-Ortega et al., 2021): This subfactor refers to the level of support and involvement of management in technology implementation. It is important because it ensures that management is committed to the implementation process and provides the necessary resources and leadership to ensure its success.

o Technology Oversight (Governance and on, 2013): This subfactor refers to the level of oversight and governance of technology implementation. It is important because it ensures that the implementation process is managed effectively, risks are identified and addressed, and quality standards are met.

o Decision-making Process (How to implement new technology in the workplace, 2022; Technology decision making, 2022): This subfactor refers to the process used by the organization to make decisions related to technology implementation. It is important because it ensures that decisions are made in a systematic and transparent way and that stakeholders are involved in the decision-making process.

o Resource Allocation (Maritan and Lee, 2017; Resource Allocation, 2022): This subfactor refers to the allocation of resources such as budget, personnel, and technology infrastructure for technology implementation. It is important because it ensures the necessary resources are available to support the implementation process.

- Personnel Training is a crucial factor that focuses on equipping employees with the necessary skills and knowledge to effectively utilize new technologies. Comprehensive training programs should cover both the technical aspects of the technologies being implemented and their practical application within the organization's context. It is vital to tailor training programs to address the specific needs of different user groups, ensuring that individuals at all levels of the organization receive appropriate training. Employing various training formats, such as workshops, hands-on sessions, and e-learning modules, maximizes employee engagement and knowledge retention, empowering them to leverage the full potential of the implemented technologies (Yazar, 2010; Molino et al., 2020; Consultancy, 2021). Some of the subfactors within Personnel Training are:

o Strategy (Lau, 2008; Tang, 2017; Xie et al., 2023): This subfactor refers to the development of a comprehensive training strategy for technology implementation. It is important because it ensures that personnel have the necessary knowledge and skills to effectively use the technology solutions.

o Delivery Mode (Buch and Bartley, 2002; Hammond, 2005; Mohammed et al., 2019): This subfactor refers to the mode of delivery for personnel training, such as in-person, online, or blended. It is important because it ensures that personnel training is delivered in a way that is effective, efficient, and accessible.

o Frequency of Training (Ongori and Nzonzo, 2011; Colman, 2021; James, 2021): This subfactor refers to the frequency of personnel training, such as one-time, periodic, or ongoing. It is important because it ensures that personnel are continuously trained and updated on the technology solutions.

o Technology Support (Lockett, 2002; Harder and Benke, 2005; Kennedy, 2008): This subfactor refers to the availability and quality of technology support for personnel during technology implementation. It is important because it ensures that personnel have the necessary support to effectively use the technology solutions and can quickly resolve any issues or challenges that may arise.

o Assessment and Evaluation (Morris, 2013; AIHR, 2022; OPM, 2022; Topno, 2022): This subfactor refers to the process of assessing and evaluating the effectiveness of personnel training for technology implementation. It is important because it helps identify personnel knowledge and skills gaps and allows for continuous training program improvement.

3 Research objective and methodology

Previous research has recognized the crucial factors necessary to implement technology within state DOTs successfully. However, there are limitations in comprehensively exploring and assessing the relative importance of these factors. As highlighted in the synthesis study (Christofer Harper Daniel Tran and Ed Jaselskis, 2019), there are research gaps concerning utilizing innovative and advanced technologies during construction delivery. Therefore, there is a need for an in-depth examination of each technology implementation factor and its impact on successful implementation within state DOTs. Moreover, while self-assessment tools exist for state DOTs to evaluate their technology implementation maturity (Tripathi et al., 2023a), these tools may not offer a detailed roadmap for improvement or encompass all the significant factors identified in the literature. Consequently, a complementary tool is required to provide a more comprehensive assessment of the six technology implementation factors and guide state DOTs towards successful technology implementation.

Hence, this research aims to address the research gaps found in previous studies (Christofer Harper Daniel Tran and Ed Jaselskis, 2019; Tripathi et al., 2023a) by conducting a comprehensive investigation of technology implementation factors and subfactors. Additionally, the research team has developed a complementary tool that complements existing self-assessment tools for state DOTs. By combining the PPT model, implementation factors, subfactors, and a maturity model, this study and paper offer a holistic approach to addressing the research gaps and advancing technology implementation in the context of state DOTs.

In this study, a mixed-methods approach is employed to examine the crucial factors necessary for successful technology implementation in state DOTs. The research design encompasses several components, including a thorough literature review to identify the pertinent subfactors associated with the six technology implementation factors. Additionally, a survey is conducted with different American Association of State

Highway and Transportation Officials (AASHTO) committees to assess the relative importance of People, Process, and Technology within each factor. Furthermore, an in-person workshop involving state DOT experts is organized to validate and enhance the individual subfactors for each implementation factor. To ensure the credibility and expertise of the participants, a rigorous process was followed for both the survey and the workshop. The research methodology employed in this study is visually represented in Figure 1 below, providing an overview of the research process.

The study also integrates the PPT (People, Process, Technology) model and survey responses to establish the suitable weight of People, Process, and Technology for the six factors of technology implementation. To gather data, a survey is created using the Qualtrics platform and distributed among various AASHTO committees. These committees encompass construction, maintenance, data management and analytics, innovation, knowledge management, and asset management. AASHTO members, who are seasoned professionals engaged in technology implementation within state DOTs, participate in the survey to provide their insights and expertise. By involving these experienced individuals, the study benefits from their firsthand knowledge and perspectives on the importance of People, Process, and Technology across different technology implementation factors. The participants were requested to evaluate and assess various implementation factors, with the aim of determining the relative weights assigned to People, Process, and Technology.

The research team, comprising individuals with experience in state DOTs, recognized the importance of defining criteria for each implementation factor. This led to the identification of a need for a model that could assess these criteria effectively. Various maturity models are widely used in other industries, like the People Capability Maturity Model, Project Management Process Maturity Model, and Capability Maturity Model Integration. These established maturity models have been modified to match the state DOTs setting and context allowing state DOTs to measure their technology implementation maturity (Tripathi et al., 2023c). Following the pattern of other maturity models, a five-level generic maturity model was developed to be applicable to both state DOTs and technologies. This model aims to demonstrate incremental improvement as an organization progresses through the levels, with each level building upon the achievements of the previous one. The levels of the model are as follows:

- Level 1 - Initiating: At this level, the state DOT has acknowledged the need for technology implementation and has started exploring potential options.
- Level 2 - Developing: At this level, the state DOT has identified specific technology requirements and has initiated the development of a plan for implementation.
- Level 3 - Defining: At this stage, the state DOT has established a clear and well-defined plan for technology implementation. This plan includes setting goals, establishing timelines, and allocating necessary resources.
- Level 4 - Managing: At this level, the state DOT has successfully implemented technology and is actively managing and optimizing its use. The focus is on effectively utilizing the technology and maximizing its benefits.
- Level 5 - Optimizing: This is the highest level of maturity, where the state DOT has fully integrated technology into its operations. At this stage, the organization continuously refines and improves its use of technology to achieve the maximum possible benefits.

The research team further delved into the six critical factors to identify four to six subfactors for each factor and to elaborate on the different levels of maturity within each factor. This comprehensive approach was adopted to gain a deep and nuanced understanding of the crucial elements contributing to successful technology implementation. The research team aimed to provide state DOTs with a detailed roadmap for successful technology implementation by pinpointing specific subfactors and delineating the various levels of maturity associated with each factor.

A face-to-face workshop was conducted to ensure the findings' accuracy and reliability. This workshop served as a platform for in-depth discussions and validation of the six implementation factors, their corresponding subfactors, and the survey results. The 18 workshop participants were meticulously selected industry professionals from different state DOTs who are in their careers' middle to late stages and possess extensive expertise and involved in implementing technology within their respective organizations. The participants were from Alabama DOT, Nevada DOT, Iowa DOT, Kentucky DOT, Montana DOT, North Carolina DOT, North Dakota DOT, Tennessee DOT, Utah DOT, South Dakota DOT, California DOT, Oregon DOT, Maryland DOT, Michigan DOT and FHWA. Their valuable insights and contributions enriched the research findings and further solidified the validity of the proposed framework. The selection process ensures a diverse representation of state DOTs, technologies, and geographical regions, enhancing the validity and generalizability of the research findings. The discussions in the workshop help validate the identified subfactors and maturity levels, ensuring that the research findings align with the practical realities and challenges faced by state DOTs in technology implementation. Their discussion, factors feedback, ranking exercise, validation and data collected through the workshop were helpful and they helped validate research findings and outcomes. Questions were similar to survey, but it was more informative and more like discussion as a group and hearing from each other along with research team collectively.

Based on the identification of subfactors and their corresponding maturity levels, a self-assessment tool was developed. This tool enables state DOTs to assess their current level of maturity for each sub-factor and compare it to the desired target level. By using the tool, state DOTs can gain insights into their current status and identify areas that require improvement or development. A radar chart for each implementation factor was also provided as part of the self-assessment tool. State DOTs can use the radar diagram as a reference point to track their progress, set goals, and measure their success in improving their technology implementation practices. The approach and methodology employed in this study were designed to be applicable to a wide range of state DOTs and adaptable to both new and existing technologies. By involving these expert participants in both survey and the workshop, this study benefits from their firsthand knowledge, unbiased perspectives, and rich experiences in technology implementation within state DOTs. Their input adds depth and credibility to the research findings, ensuring the proposed framework and assessment

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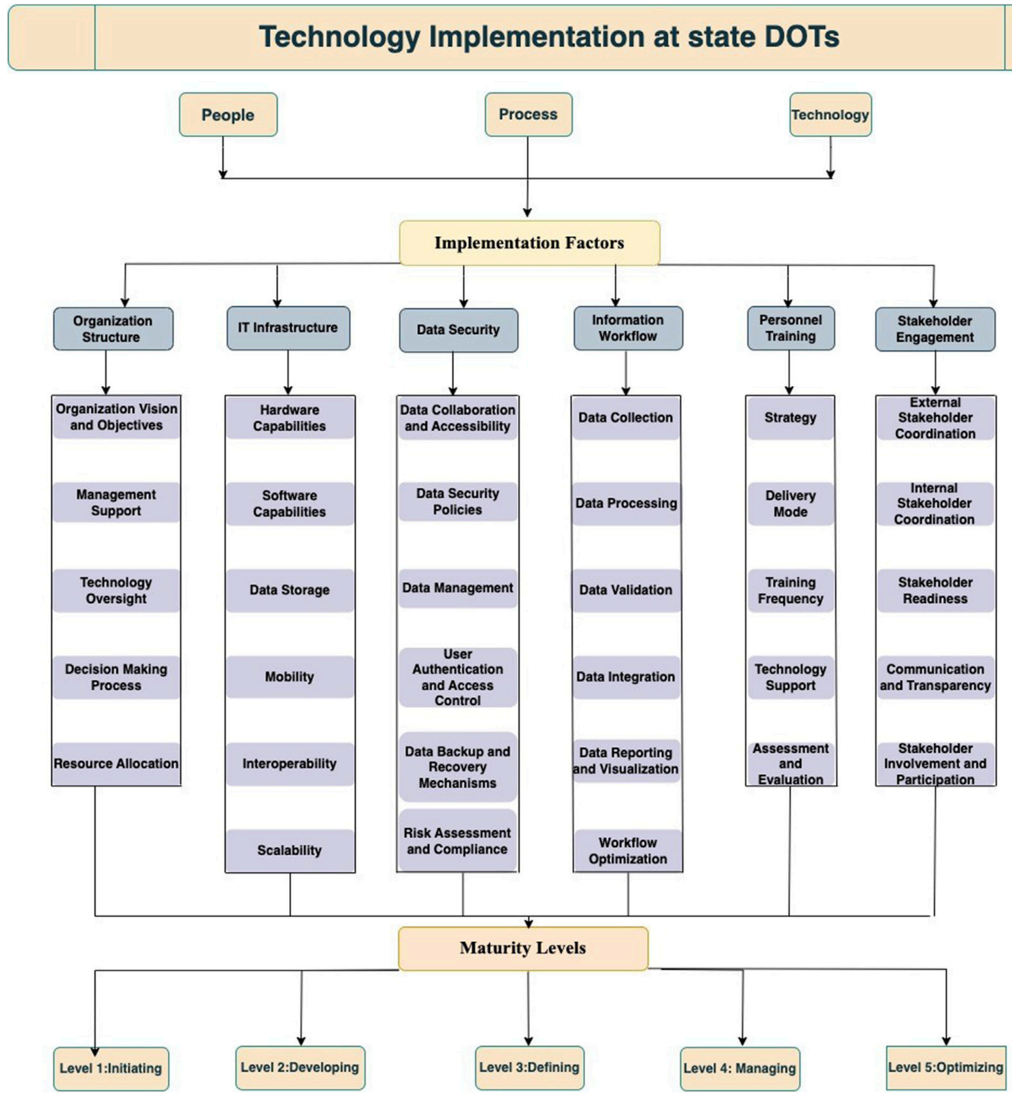

FIGURE 1
Research methodology.

tool are grounded in the practical realities of technology implementation within state DOTs.

4 Results

This section delves into the study's findings, focusing on the assessment and analysis of the critical success factors and the weighting of People, Process, and Technology, as well as their respective subfactors necessary for the successful implementation of technology. Drawing from the overall rankings (Bilge et al., 2014), the results section provides a detailed exploration of each implementation factor, including an in-depth examination of the relative importance and maturity levels assigned to People, Process, and Technology. Furthermore, it concisely defines the identified subfactors, presents a five-level maturity framework for each subfactor, and introduces a self-assessment tool and radar diagram to facilitate evaluation.

As previously described in the methodology section, the research team devised five distinct maturity levels for each sub-factor. This framework was developed to enable benchmarking and goal setting, providing a clear roadmap for state DOTs to gauge their progress and establish targets throughout the technology implementation process. Figure 2 shows the weight of People, Process, and Technology for six factors, and further explained in the following paragraphs. The weights of People, Process and Technology were calculated from 74 survey responses of different AASHTO committees and subcommittees members. Different participants had different views based on their experience. The sum of weights of People, Process and Technology for each factor was equal to 100%. The average of weight of people refers to the relative importance of people in technology implementation process. It is part of a broader analysis that involves assigning weights to the impact of people, process, and technology dimensions on the implementation process.

5 Implementation factors and weights

5.1 Implementation success factor: stakeholder engagement

The examination of the weighting factor for stakeholder engagement reveals that People hold the highest level of significance, accounting for 58% of the overall importance. Process and Technology are secondary factors, weighing 23% and 19%, respectively. These findings underscore the critical role played by human factors, including effective communication, collaboration, and leadership, in achieving successful stakeholder engagement during technology implementation. The study emphasizes the importance of well-defined processes in facilitating stakeholder engagement while highlighting that technology should serve as a supporting tool rather than the primary driver. Overall, these results emphasize the need for a people-centric approach, where effective processes take precedence, with technology playing a complementary role, in ensuring successful stakeholder engagement.

5.2 Implementation success factor: organization structure

Based on the analysis of the weighting factor for Organization Structure, it is evident that People carry the highest level of significance with a weight of 47%. Process and Technology, on the other hand, are considered secondary factors, accounting for weights of 35% and 18%, respectively. These findings highlight the critical role of human factors, such as management support and technology oversight in successful organization structure for technology implementation. The study emphasizes the importance of well-defined processes in facilitating the desired structure while emphasizing that technology should serve as a supportive tool rather than the primary driver. Overall, these results emphasize the need for a people-centric approach, where the focus is on effective processes with technology playing a complementary role, to ensure a robust organizational structure for successful technology implementation.

5.3 Implementation success factor: IT infrastructure

Upon examining the weighting factor for IT Infrastructure, it becomes apparent that Technology bears the greatest significance level, with a weight of 45%. Process and People, however, are regarded as secondary factors, carrying weights of 28% and 27%, respectively. These findings emphasize the critical role of technology in IT infrastructure, highlighting the importance of selecting and implementing appropriate hardware, software, and network infrastructure. Process and People, while still significant, play supportive roles in ensuring the efficient operation and management of the IT infrastructure. This underscores the need for well-defined processes and skilled individuals to effectively handle the technology and maintain its optimal functioning. Overall, these results highlight the importance of technological considerations in IT infrastructure, supported by effective processes and knowledgeable personnel.

5.4 Implementation success factor: data security

Upon analyzing the weighting factor for Data Security, it becomes apparent that Technology holds the highest significance level, with a weight of 47%. Process and People, on the other hand, are regarded as secondary factors, carrying weights of 30% and 24%, respectively. These findings underscore the critical role of technology in ensuring data security, highlighting the importance of robust security measures, encryption techniques, access controls, and data backup mechanisms. Process and People, while still significant, contribute to the overall data security framework by implementing and enforcing security policies, conducting regular audits, and raising awareness about

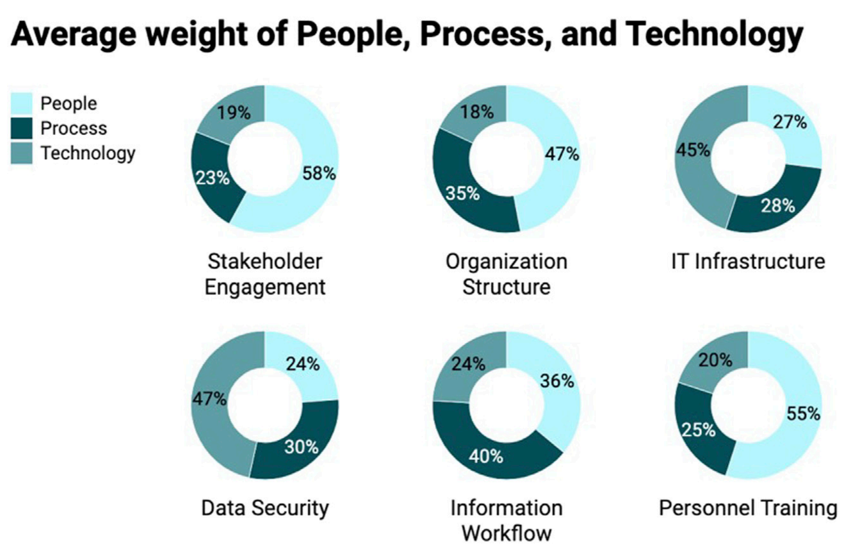

FIGURE 2
Average weight of People, Process, and Technology for six factors.

data protection practices. This emphasizes the need for a comprehensive approach that combines effective technology solutions, well-defined processes, and trained personnel to safeguard sensitive information. Overall, these results highlight the importance of technological measures supported by process controls and skilled individuals in maintaining robust data security.

5.5 Implementation success factor: information workflow

Upon analyzing the weighting factor for Information Workflow, it becomes apparent that Process holds the highest significance level, with a weight of 40%. People and Technology, on the other hand, are considered secondary factors, carrying weights of 36% and 24%, respectively. These findings emphasize the crucial role of well-defined processes in effectively managing information workflow during technology implementation. Process factors such as data collection, processing, validation, integration, reporting, and workflow optimization play a pivotal role in ensuring smooth and efficient information flow within the organization. People factors, including skilled personnel, training, and collaboration, contribute to the successful execution of these processes. Technology serves as a supporting tool, enabling automation, integration, and visualization of information. The results highlight the need for organizations to prioritize process optimization and align their technology and human resources to achieve efficient information workflow.

5.6 Implementation success factor: personnel training

After examining the weighting factor for Personnel Training, it is clear that People have the highest significance level, with a weight of 55%. Process and Technology, on the other hand, are considered secondary factors, carrying weights of 25% and 20%, respectively. These findings emphasize the crucial role played by individuals in successful personnel training for technology implementation. Effective training strategies, delivery modes, and frequency of training contribute to the development of a skilled and knowledgeable workforce. The establishment of support systems and technology infrastructure enhances the training process, enabling efficient delivery and assessment. However, it is important to recognize that the emphasis should be placed on the people themselves, ensuring they possess the necessary skills, competencies, and support to effectively utilize technology. By prioritizing people, organizations can foster a culture of continuous learning and improvement, ultimately maximizing the benefits of personnel training in technology implementation.

5.7 Self-Assessment tool for technology implementation factors

Based on the determined maturity levels, a self-assessment tool can be developed for all six factors of technology implementation. The literature extensively employs maturity models for assessing technology implementation. In comparison to existing literature, this study offered a tailored approach by developing a generic maturity model specifically for state DOTs and technologies. This customized framework addresses the unique challenges and needs of state DOTs, providing a comprehensive roadmap for technology implementation that may differ from more generic models found in the literature. Figure 3 displays a radar chart depicting the assessment of the five subfactors associated with Organization Structure. Other radar charts for other factors can be created similarly. Each subfactor are evaluated on a five-level maturity scale, as shown in Table 2 for Stakeholder Engagement, Table 3 for Organization Structure, Table 4 for IT Infrastructure, Table 5 for Data Security, Table 6 for Information Workflow, and Table 7 for Personnel Training. The target levels presented in the chart and table are determined based on the collective levels identified during the

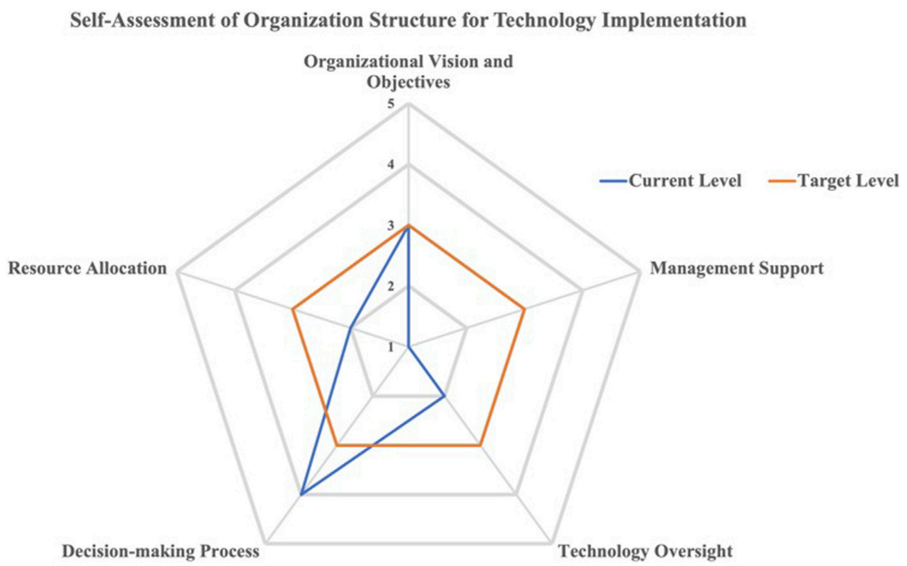

FIGURE 3
Self-assessment of organization structure for technology implementation.

TABLE 2 Implementation success factor for stakeholder engagement.

Implementation success factor: Stakeholder engagement						
Subfactors	Level 1: Initiating	Level 2: Developing	Level 3: Defining	Level 4: Managing	Level 5: Optimizing	Target level
External Stakeholder Coordination	Informed - Stakeholders are provided with basic information on technology implementation through generic communication channels such as newsletters and websites	Consulted - Stakeholders are occasionally asked for feedback and input through surveys or other forms of communication	Involved - Stakeholders are actively engaged in the technology implementation process through focus groups, community meetings, and other forms of direct communication	Collaborative - Stakeholders are directly involved in decision-making processes related to technology implementation, and their feedback is considered in making final decisions	Empowered - Stakeholders strongly influence technology implementation decisions, and their needs and desires shape the project. Stakeholders are viewed as partners in the project rather than simply recipients of the information	Level 2
Internal Stakeholder Coordination	Informed - Internal stakeholders are notified of the technology implementation after decisions have already been made, with no opportunity for input	Consulted - Internal stakeholders are occasionally consulted for input during technology implementation decision-making processes	Involved - Internal stakeholders are regularly involved in technology implementation decision-making processes	Collaborative - Internal stakeholders have direct representation on technology implementation committees and actively collaborate on decision-making processes	Empowered - Internal stakeholders are encouraged to actively participate in decision-making processes and have a strong influence on technology implementation decisions	Level 3
Stakeholder Readiness	Unaware - Stakeholders are not aware of the technology implementation plan or its potential benefits	Resistant - Stakeholders are aware of the technology implementation plan but are actively resistant to it	Neutral - Stakeholders are aware of the technology implementation plan but are not actively supportive or resistant	Supportive - Stakeholders are aware of the technology implementation plan and are actively supportive of it	Leading - Stakeholders not only actively support the technology implementation plan but also take a leadership role in promoting and implementing it	Level 3
Communication and Transparency	No Communication - There is no communication or transparency provided to stakeholders	Basic Communication - Basic communication is provided to stakeholders, but transparency is limited	Informative Communication - Stakeholders are informed about the technology implementation progress, and transparent communication is provided	Proactive Communication - Proactive communication is provided to stakeholders, and their feedback is solicited to improve the implementation process	Collaborative Communication - Stakeholders are actively involved in the communication process and contribute to decision-making regarding technology implementation. Transparency is provided at all stages, and there is a high degree of collaboration between stakeholders and the implementation team	Level 3
Stakeholder Involvement and Participation	No involvement or participation: Stakeholders are not engaged in the implementation process	Limited involvement or participation: Stakeholders are informed of the implementation process but have limited opportunities to provide feedback or suggestions	Occasional involvement or participation: Stakeholders are provided with regular opportunities to provide feedback and suggestions but are not consistently engaged throughout the implementation process	Consistent involvement or participation: Stakeholders are consistently engaged and involved in the implementation process through regular meetings, feedback sessions, and collaborative decision-making	Active involvement or participation: Stakeholders are active participants in the implementation process, with a strong sense of ownership and investment in the project's success. They are involved in all aspects of the implementation process and contribute significantly to decision-making and problem-solving	Level 3

workshop. The research team with experience and expertise in technology implementation referenced different maturity models and defined generic maturity model applicable to both state DOTs and technologies. These models aim to demonstrate incremental improvement as an organization progresses through the levels, with each level building upon the achievements of the previous one. This framework was developed to enable benchmarking and goal setting, providing

TABLE 3 Implementation success factor for organization structure.

Implementation success factor: Organization structure						
Subfactors	Level 1: Initiating	Level 2: Developing	Level 3: Defining	Level 4: Managing	Level 5: Optimizing	Target level
Organizational Vision and Objectives	Unaware- No established vision or objectives for the technology implementation	Resistant- Vision and objectives are established, but not aligned with the organization's overall goals	Neutral - Vision and objectives are established and aligned with the organization's overall goals	Supportive - Vision and objectives are established, aligned with the organization's overall goals, and communicated effectively	Leading -Vision and objectives are constantly reviewed and updated based on changing organizational needs and technology advancements	Level 3
Management Support	No Support - Management is not aware of or does not support the technology implementation	Limited Support - Management provides limited support and does not prioritize the technology implementation	Moderate Support - Management shows moderate support and prioritization for the technology implementation but lacks a clear plan or strategy for implementation	Strong Support - Management provides strong support and prioritization for the technology implementation, with a clear plan and strategy for implementation	Active promotion - Management actively promotes the technology implementation throughout the organization and ensures that the necessary resources and support are in place to achieve success	Level 3
Technology Oversight	Unaware - No established oversight or champion for technology implementation	Resistant - Established oversight or champion, but not effective or efficient	Neutral - Effective oversight/champion, periodically reviewed and updated	Supportive -Effective oversight/champion, incorporates best practices, seeks feedback	Leading - Proactively adapts oversight/ champion structure based on changing needs/ advancements	Level 3
Decision-making Process	Reactive - Decisions are made in reaction to immediate needs or issues without a clear strategy or plan	Ad hoc - Decisions are made on an *ad hoc* basis, without clear guidelines or standard procedures	Structured - Decisions are made using a structured approach, with clear guidelines and procedures in place	Integrated - Decisions are made in an integrated manner, taking into account multiple perspectives and considering long-term consequences	Strategic - Decisions are made in a strategic manner, aligned with the organization's overall goals and objectives, and with a focus on innovation and continuous improvement	Level 3
Resource Allocation	Inadequate - No allocated resources for the technology implementation	Insufficient - Limited resources allocated for the technology implementation	Adequate - Resources allocated for the technology implementation are sufficient	Sufficient - Resources allocated for the technology implementation are more than sufficient	Optimal - Resources allocated for the technology implementation are constantly reviewed and adjusted based on changing organizational needs and the technology implementation progress	Level 3

a clear roadmap for state DOTs to gauge their progress and establish targets throughout the technology implementation process.

It should be noted that while most scores were identified during the workshop, certain scores were not specifically addressed. In such cases, these scores were assessed and determined by experts with extensive knowledge and experience in the field of DOT implementation. The current levels used in this tool are provided for demonstration purposes only, showcasing how the tool operates and functions. The blue line represents the mock maturity level of the state DOTs, while the orange line represents the target levels.

6 Discussion

The provided self-assessment tool, which includes the tables and radar diagrams, provide state DOTs to evaluate different subfactors within six implementation factors and determine their desired target levels in comparison to their current levels. This tool also considers the weighting assigned to People, Process, and Technology, providing a comprehensive understanding of the critical factors required for successful technology implementation. The analysis of the weighting factors for each major implementation factor provides valuable insights into the areas where time and effort need to be focused. By assessing the subfactors within each major implementation factor, transportation agencies can prioritize their efforts and allocate resources accordingly to achieve the targeted maturity level for technology implementation. These assessments can be combined as a workbook-type assessment for state DOTs to prepare and assess their potential technology implementations.

Stakeholder Engagement emerged as a critical factor, with People as the most significant contributor, carrying a weight of 58% overall importance. The identified subfactors, including external and internal stakeholder coordination, stakeholder

TABLE 4 Implementation success factor for IT infrastructure.

Implementation success factor: IT infrastructure						
Subfactors	Level 1: Initiating	Level 2: Developing	Level 3: Defining	Level 4: Managing	Level 5: Optimizing	Target level
Hardware Capabilities	Foundational - Investigating hardware options and capabilities	Basic - Piloting one or more hardware options	Intermediate - Limited access to hardware - *ad hoc* procurement of hardware per team's preference	Advanced - Hardware has been standardized for enterprise and procurement is managed efficiently	Expert - Enterprise hardware replacement cycle program is established, continuously reviewed, and updated based on changing organizational needs and technology advancements	Level 3
Software Capabilities	Foundational - Investigating software options and capabilities	Developing - Piloting one or more software options	Standardizing - Limited access to software - *ad hoc* procurement of software per team's preference	Advanced - Software has been standardized for enterprise and procurement is managed efficiently	Mature - Enterprise software management program is established and continuously reviewed and updated based on changing organizational needs and technology advancements	Level 3
Data Storage	Initial - Data storage is managed *ad hoc* and not centrally managed	Managed - Limited data storage is centrally managed	Defined - Centralized data storage exists but is not optimized	Optimizing- Optimized centralized data storage is in place	Innovating - Scalable and highly available centralized data storage is in place, with regular reviews and updates to ensure continued efficiency and effectiveness	Level 3
Mobility	Nonexistent - No mobile devices or services are provided	Ad hoc - Mobile devices are provided on an *ad hoc* basis without a centralized management system	Basic - A centralized mobile device management system is in place, but devices are limited to email and basic communication capabilities	Standardized - An enterprise-wide mobile device program is established with standardized devices, applications, and a centralized management system	Advanced - Advanced mobile capabilities are in place, such as mobile applications, secure access to enterprise resources, and integration with other systems. The program is continuously reviewed and updated based on changing organizational needs and technology advancements	Level 4
Interoperability	Initial - Little to no focus on interoperability	Ad hoc - Some interoperability efforts are underway but not yet established	Defined - Interoperability is established between some systems, but not all	Managed - Interoperability is established between most systems	Optimized - Interoperability is established between all systems, with a proactive approach to adding new systems and ensuring continued effectiveness	Level 3
Scalability	Initial - Little to no consideration for scalability	Ad hoc - Some consideration for scalability but no formal strategy in place	Defined - Scalability is considered in technology decision-making, but not formally integrated into enterprise architecture	Managed - Scalability is formally integrated into enterprise architecture	Optimized - Scalability is optimized through proactive monitoring, testing, and continuous improvement processes. Scalability is a key consideration in all system and application design and development efforts	Level 4

readiness, communication and transparency, and stakeholder involvement and participation, provide actionable areas for state DOTs to prioritize and improve upon in their technology initiatives. The self-assessment tool developed as part of this study can be utilized by State DOTs to evaluate their current level of stakeholder engagement and set targets for improvement based on the identified subfactors and maturity levels.

In terms of Organization Structure, People were again identified as the primary driver, accounting for 47% of the overall importance. The subfactors, including organizational vision and objectives, management support, technology oversight, decision-making processes, and resource allocation, play a crucial role in shaping the organization's structure for technology implementation. State DOTs can utilize the self-assessment tool to assess their current organizational structure, identify areas for improvement, and set targets for achieving desired maturity levels.

IT Infrastructure was found to be primarily driven by Technology, carrying a weight of 45% in overall importance. The subfactors

TABLE 5 Implementation success factor for data security.

Implementation success factor: Data security						
Subfactors	Level 1: Initiating	Level 2: Developing	Level 3: Defining	Level 4: Managing	Level 5: Optimizing	Target level
Data Collaboration and Accessibility	Limited - No ability to share data with external resources	Ad hoc - Ability to transfer information on a one-time basis, data not managed (e.g., ftp downloads)	Defined - Internal access to web-based/cloud-based services	Managed - Security restricted and reviewed cloud-based services	Optimized - Unrestricted cloud-based services (SAAS)	Level 3
Data Security Policies	Inadequate - No policies or guidelines for data security	Ad hoc - Informal or undocumented policies for data security	Defined - Formal policies and guidelines for data security are in place	Managed - Policies are reviewed and updated regularly to ensure their effectiveness	Optimized - Continuous improvement of policies and guidelines based on changing security threats and risk assessments	Level 4
Data Management	Inadequate - No formal data management practices in place	Ad hoc - Informal or undocumented data management practices	Defined - Formal data management practices are in place	Managed - Data management practices are reviewed and updated regularly to ensure their effectiveness	Optimized - Continuous improvement of data management practices based on changing organizational needs and technological advancements	Level 3
User Authentication and Access Control	Initial -No authentication or access control measures in place	Ad hoc - Informal authentication or access control measures in place	Defined - Formal authentication and access control policies in place, but not integrated into overall enterprise architecture	Managed - Formal authentication and access control policies integrated into overall enterprise architecture	Optimized - Authentication and access control policies are reviewed and updated regularly to align with evolving threats and organizational needs	Level 3
Data Backup and Recovery Mechanisms	Initial -No formal backup and recovery mechanisms in place	Ad hoc - Basic backup and recovery mechanisms in place, but not consistent or standardized	Defined - Formalized and standardized backup and recovery mechanisms in place	Managed -Automated backup and recovery mechanisms in place	Optimized Continuous improvement of backup and recovery mechanisms through regular assessment and optimization	Level 3
Risk Assessment and Compliance	Initial - No formal risk assessment or compliance processes in place	Ad hoc -Some risk assessment and compliance processes in place, but not consistently applied or monitored	Defined -Formal risk assessment and compliance processes in place, consistently applied and monitored	Managed - Continuous risk assessment and compliance monitoring, with periodic review and adjustment of processes based on identified risks and compliance requirements	Optimized - Proactive risk management and compliance monitoring, with a focus on identifying and mitigating potential risks before they occur. Continuous improvement of risk assessment and compliance processes, leveraging industry best practices and emerging technologies	Level 3

identified, such as hardware capabilities, software capabilities, data storage, mobility, interoperability, and scalability, provide specific areas for assessment and improvement. State DOTs can utilize the self-assessment tool to evaluate their IT infrastructure capabilities, identify gaps, and develop strategies for enhancement.

In the realm of Data Security, Technology was identified as the most significant factor, carrying a weight of 47% in overall importance. The subfactors, including data collaboration and accessibility, data security policies, data management, user authentication and access control, data backup and recovery mechanisms, and risk assessment and compliance, provide areas for evaluation and improvement. State DOTs can utilize the self-assessment tool to assess their data security measures, identify vulnerabilities, and implement appropriate technological and process-related solutions.

Information Workflow, on the other hand, was primarily driven by the Process, with a weight of 40% in overall importance. The identified subfactors, including data collection, data processing, data validation, data integration, data reporting, and data visualization, provide specific areas for assessment and improvement. State DOTs can utilize the self-assessment tool to evaluate their current information workflow processes, identify bottlenecks or inefficiencies, and set targets for achieving desired maturity levels.

Finally, Personnel Training emerged as a critical factor, with People carrying the highest level of significance, accounting for 55% of the overall importance. The identified subfactors, including training needs assessment, training program development, training delivery, training evaluation, and continuous learning, provide areas for evaluation and improvement. State DOTs can utilize the self-assessment tool to assess their current personnel

TABLE 6 Implementation success factor for information workflow.

Implementation success factor: Information workflow						
Subfactors	Level 1: Initiating	Level 2: Developing	Level 3: Defining	Level 4: Managing	Level 5: Optimizing	Target level
Data Collection	Ad hoc - No standards or procedures for data collection platforms. Rely on consultant/ service provider to acquire data	Developing - Initial standards and procedures for data collection platforms are being explored	Defined - Standards and procedures for data collection platforms are being developed	Managed - Standards and procedures for each type of data collection platform are documented and institutionalized for both internal agency and consultants	Optimized - Continuous improvement of data collection platforms through feedback mechanisms and incorporation of emerging technologies to ensure best practices are always being implemented	Level 4
Data Processing	Ad hoc - No data processing plan or procedures in place	Repeatable - Basic data processing procedures in place, but *ad hoc* and not standardized	Defined - Standardized data processing procedures in place, with some level of automation	Managed - Advanced data processing procedures in place, with automated workflows and real-time processing capabilities	Optimized - State-of-the-art data processing procedures in place, with predictive analytics and machine learning capabilities	Level 4
Data Validation	Unaware - No data validation procedures in place. All data accepted as is	Basic - Some data validation procedures exist, but not consistently applied	Defined - Data validation procedures are being developed. Agency staff collaborating with industry	Managed - Data validation procedures are in place and consistently applied	Optimized - Data validation procedures are documented and institutionalized for both internal agencies and consultants and automated where possible	Level 4
Data Integration	Initial -No data integration procedures in place. Data siloed in various databases or spreadsheets	Ad hoc - Some data integration procedures exist, but not consistently applied	Defined -Data integration procedures are being developed. Agency staff collaborating with industry	Managed -Data integration procedures are in place and consistently applied	Optimized - Data integration procedures are documented and institutionalized for both internal agency and consultants, and automated where possible	Level 3
Data Reporting and Visualization	Initial -No standardized reports or visualizations available. Reports and visualizations are *ad hoc* and manually created	Ad hoc - Some standardized reports or visualizations exist, but not consistently applied	Defined - Standardized reports and visualizations are being developed. Agency staff collaborating with industry	Managed -Standardized reports and visualizations are in place and consistently applied	Optimized- Standardized reports and visualizations are documented and institutionalized for both internal agency and consultants, and automated where possible	Level 3
Workflow Optimization	Initial - No systematic approach to workflow optimization. Workflows are *ad hoc* and not optimized	Ad hoc -Some workflow optimization efforts exist, but not consistently applied	Defined -Workflow optimization efforts are being developed. Agency staff collaborating with industry	Managed - Workflow optimization efforts are in place and consistently applied	Optimized - Proactive risk management and compliance monitoring, with a focus on identifying and mitigating potential risks before they occur. Continuous improvement of risk assessment and compliance processes, leveraging industry best practices and emerging technologies	Level 3

training programs, identify gaps or areas for enhancement, and set targets for achieving desired maturity levels.

The findings of this study emphasize the need for a balanced approach to technology implementation, considering the interplay of People, Process, and Technology. While each factor carries a different weight of importance, the success of technology implementation relies on the integration and optimization of all three factors. The identified subfactors and the self-assessment tool offer practical guidance for State DOTs to evaluate their current status, identify areas for improvement, and set targets for achieving desired maturity levels in technology implementation. As identified in various literature sources, both People and Process emerge as pivotal factors for successful technology implementation. Acknowledging that Technology alone is not sufficient, the effective interplay and emphasis on People, Process and Technology ensure successful implementation.

Additionally, the subfactors assessment tool developed in this study serves as a complementary tool to a higher-level People-Process-Technology (PPT) model identified in previous research and shown in Figure 4. The PPT model, which recognizes the critical role of People, Process, and Technology in technology implementation, provides a framework for understanding the interdependencies and interactions

TABLE 7 Implementation success factor for personnel training.

Implementation success factor: Personnel training						
	Level 1: Initiating	Level 2: Developing	Level 3: Defining	Level 4: Managing	Level 5: Optimizing	Target level
Strategy	Ad hoc - Training is available from vendors or service providers only. Individual project teams coordinate with service provider to receive training and technical support	Basic - A train the trainer program is in place. Technical champion coordinates with vendor or service provider to provide training	Structured - Technology champion has a small group of training staff to perform statewide training	Advanced - Agency collaborating with industry to develop a certification program	Optimal - Established agency-specific certification program	Level 3
Delivery Mode	Instructor -Led - In-person training only	Blended - Webinars and online training modules are available	Virtual - Training is available on-demand, including webinars, online training modules, and virtual classroom sessions	Mobile - Blended learning approaches are utilized, combining in-person and virtual training	Personalized - Advanced use of technology for training delivery, including virtual and augmented reality simulations	Level 2
Frequency of Training	Ad hoc - No formal training schedule, training offered only as needed	Regular - Regular training schedule established, with courses offered quarterly or bi-annually	Frequent - Training is offered on a monthly basis, with some courses offered more frequently	Comprehensive- A comprehensive training schedule is established for each fiscal year, with courses offered on a weekly or bi-weekly basis	Continuous - Continuous training is provided throughout the year, with ongoing opportunities for staff to refresh and update their skills	Level 2
Technology Support	Minimal - No dedicated technology support for training	Basic - Basic technology support available for training, such as troubleshooting of hardware and software issues	Advanced - Advanced technology support available for training, including access to specialized software and hardware	Robust- Technology support staff are integrated into the training team, providing assistance with course development and delivery	Cutting Edge - Comprehensive technology support infrastructure is in place, including a dedicated help desk, instructional design team, and learning management system	Level 2
Assessment and Evaluation	Basic - No formal evaluation process in place	Developing - Basic evaluation process in place, including participant feedback surveys	Intermediate - More advanced evaluation process in place, including follow-up assessments and training impact evaluations	Advanced - Robust evaluation process in place, with ongoing monitoring and evaluation of training programs and participant progress	Exemplary - Comprehensive evaluation process in place, including evaluation of the effectiveness of training on overall agency performance and outcomes, and incorporation of evaluation feedback into continuous improvement efforts	Level 3

among these factors. The subfactors assessment tool builds upon this model by offering a more granular and detailed analysis of the specific subfactors within each major implementation factor. The subfactors assessment tool enhances the applicability and practicality of the PPT model by providing a standardized framework for self-assessment. This self-assessment capability empowers transportation agencies to take ownership of their technology implementation journey and make informed decisions based on their specific strengths and areas for improvement. The self-assessment tool and radar diagrams are flexible and can accommodate various technologies, including both current and emerging.

The in-person workshop participants, who were experts from various state DOTs, found the subfactors assessment tool to be highly interesting and valuable for technology implementation. Their feedback and insights during the workshop indicated that the tool provided a structured and systematic approach to assess and prioritize the critical subfactors within each major implementation factor. They found the tool to be intuitive and user-friendly, enabling them to easily navigate through the subfactors and assess their maturity levels. The positive feedback from the workshop participants suggests that the subfactors assessment tool has practical utility and can be a valuable resource for state DOTs in their technology implementation efforts. The participants also recognized the tool's value in facilitating discussions and decision-making within their respective state DOTs. The standardized assessment framework provided a common language and reference point for collaboration among stakeholders, fostering a shared understanding of the critical factors and subfactors that contribute to successful technology implementation.

7 Conclusion

In conclusion, this study aimed to assess and analyze the critical success factors for technology implementation in state DOTs, focusing

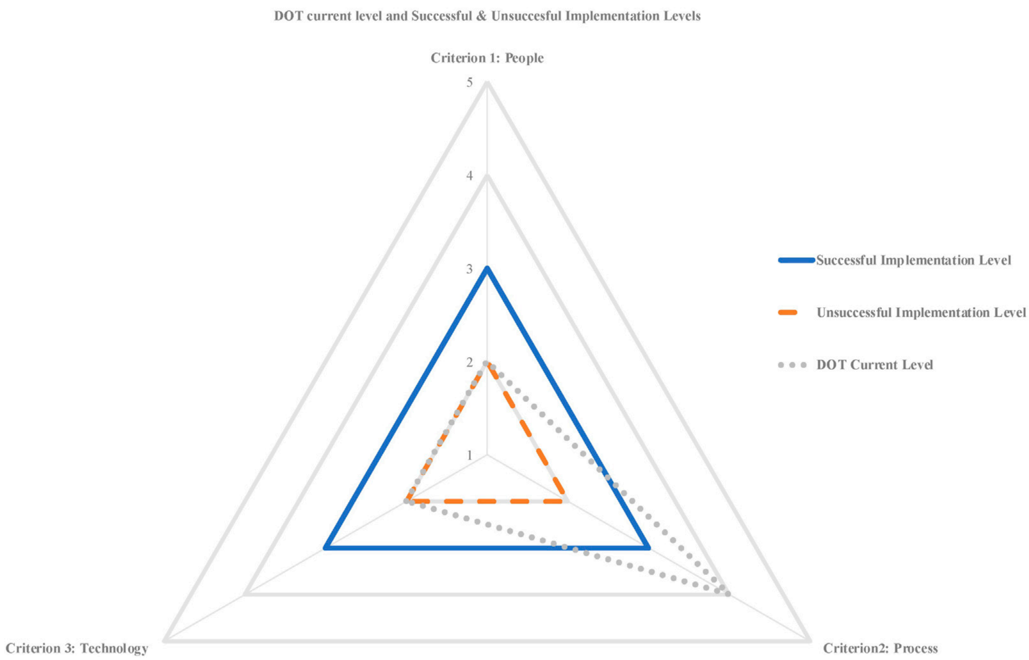

FIGURE 4
PPT-based Self-Assessment Tool for Technology Implementation (adapted from Tripathi et al., 2023)

on six key factors: Stakeholder Engagement, Organization Structure, IT Infrastructure, Data Security, Information Workflow, and Personnel Training. Through a comprehensive analysis of the weighting factors and subfactors, as well as the development of a self-assessment tool, valuable insights have been gained to support successful technology implementation in the transportation sector.

The findings of this study underscore the significance of People as the primary driver across multiple implementation factors. Effective communication, collaboration, leadership, and a capable workforce are crucial in achieving successful stakeholder engagement, shaping organizational structure, and ensuring personnel training. It is evident that a people-centric approach is essential for the successful implementation of technology initiatives in State DOTs.

Additionally, Process and Technology emerged as important secondary factors, highlighting the importance of well-defined processes and the appropriate utilization of technology as a supporting tool. State DOTs must establish robust processes for stakeholder engagement, IT infrastructure management, data security, information workflow, and personnel training to optimize the benefits of technology implementation.

Overall, the findings of this study and the developed self-assessment tool provide transportation agencies with valuable insights and resources to prioritize their efforts and achieve targeted maturity levels in technology implementation. By focusing on a people-centric approach, leveraging well-defined processes, and utilizing technology as a supporting tool, state DOTs can enhance stakeholder engagement, optimize organizational structures, improve IT infrastructure, ensure data security, streamline information workflow, and enhance personnel training. Ultimately, these efforts will contribute to the successful implementation of technology initiatives, leading to improved transportation systems and services for the benefit of the public.

Despite the valuable insights gained from this study, there are some limitations to consider. Although the average weights of People, Process, and Technology obtained from the survey and workshop were found to be fairly similar, there is still a potential for bias or variability in the participants' perceptions and judgments. The study focused on a specific set of critical success factors and subfactors, and there may be additional factors that were not included in the analysis. Future research could explore other relevant factors that might influence the success of technology implementation in state DOTs. The approach developed within the study involves a self-assessment using maturity models. One limitation of the approach used in this study is the potential subjectivity introduced through self-assessment, as participants evaluate their own organization's performance based on their own perspectives. However, it is important to note that these participants are experienced end users of the tool, which brings valuable insights despite the subjectivity. While some of the validation efforts in this study focused on specific technologies, it is important to acknowledge that the results presented here are generalized findings. The data and analysis encompassed a wide range of state DOTs and technology implementation factors, allowing for broader applicability and insights across various contexts. However, it is worth noting that future research could delve deeper into specific technologies or industries to explore their unique challenges and success factors in greater detail. This would provide a more nuanced understanding and further enhance the practicality and relevance of the findings for specific technology implementation initiatives. Future research could explore more into the specific strategies and best practices employed at state DOTs that have successfully implemented technologies. Future research could also explore other technology implementation factors.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary materials, further inquiries can be directed to the corresponding author.

Author contributions

AT: Conceptualization, Formal Analysis, Methodology, Validation, Writing–original draft, Writing–review and editing. RS: Conceptualization, Investigation, Project administration, Resources, Supervision, Validation, Writing–review and editing. GD: Conceptualization, Methodology, Supervision, Validation, Writing–review and editing. HN: Investigation, Methodology, Supervision, Validation, Writing–review and editing. AM: Validation, Writing–review and editing.

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Conflict of interest

Author AM is employed by HDR Inc.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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