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Evaluation of E-Ticketing Technology in Construction of Highway Projects: A Systematic Review of Adoption Levels, Benefits, Limitations and Strategies

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Highway and bridge construction projects are subject to cost and schedule overruns, as well as workforce shortages in remote locations, both of which can result in disputes over the quality of the end product. E-ticketing technology can improve the quality, however, while decreasing cost overruns and schedule delays. Despite the benefits of E-ticketing, many state departments and agencies are unwilling to transition into this technology. This study aims to identify the potential barriers to implementing E-ticketing, determine the adoption rate of state agencies/departments, and evaluate the benefits of employing an E-ticketing platform. The changes in technological trends in highway construction that are related to material tracking, inspection, and digitization are qualitatively analyzed, using meta-synthesis and interpretative analytical techniques. Key technologies that have the potential to be integrated into the E-ticketing platform to mitigate the limitations faced at the time of implementation are also discussed. The study's findings suggest that the implementation process and regulations of an E-ticketing platform vary drastically from state to state, and a common set of guidelines is essential for obtaining long term success. The study advocates four key recommendations for widespread implementation of the E-ticketing platform and suggests directions for further research. The results of this study will assist DOT's decision-makers and engineers in developing a common E-ticketing platform, adopting policies and guidelines, decreasing the costs of their projects, providing the initial investment, running pilot tests, enhancing the safety of their inspectors, and completing their projects in a timely and efficient manner.

Keywords: technology, highway, e-ticketing, material delivery, inspection

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1 INTRODUCTION

The history of evolution and today's rapid pace of development has programmed many to continually strive hard, stand out, operate intensely, build quickly, and expand their areas of creativity. Construction workers and architects constantly try to execute innovative and novel ideas in construction projects that are becoming more complex and massive (Alshawi and Faraj 2002; Stoyanova 2020). Governments have invested substantial financial resources in creating and improving road networks, as roads are a critical component of transportation systems, and digitalization is paving the way for significant changes in the way infrastructure is created, operated, and financed, and has far-reaching implications across a project's lifecycle (Alaloul et al., 2018; Cruz and Sarmento 2018). There has been resistance against digitalization in the construction of transportation infrastructure projects. In response to quality, safety, and production issues, most industries, including manufacturing, entertainment, and services, are turning to emerging technologies, resulting in some of them seeing significant gains in performance and quality (Holt et al., 2015). The construction sector is well-known for its quality, safety, and budget issues that impact a project's operating life, and non-conformance quality issues may result in penalties that impose cost and schedule overruns that are associated with reworks (Haupt and Whiteman 2004).

Since the 1990s, researchers have investigated how to leverage mobile technology to decrease the amount of administrative efforts required for construction field documentation (McCullouch and Gunn 1993; Liu 2000; Saidi et al., 2002; Kim et al., 2016; Rouhanizadeh and Kermanshachi 2020). The construction industry has always faced technology implementation challenges (Bossink 2004). Even though digitalization can substantially impact road construction there are legal, regulatory, institutional, technological, and economic hurdles to the digitalization of transportation projects (Ogunrinde et al. 2020). This study considers those hurdles and looks at how E-ticketing technology might alleviate issues pertaining to cost overruns, schedule delays, safety-related accidents, workforce shortages, quality issues, and social distancing encountered in transportation projects. Previous researchers have underlined the need for sufficient knowledge and data regarding the adoption and implementation of an E-ticketing application (Patel et al., 2019; Li et al., 2020), including potential benefits, barriers and drivers of adoption.

Technology has enabled more rapid, more accurate, and more efficient highway construction, and nationwide, researchers continue to investigate methods that will advance the operational and managerial effectiveness even further (Subramanya and Kermanshachi 2022). FHWA Everyday Counts-2 (EDC2), for instance, has shown that combining and integrating 3D modelling with GPS for machine control enables DOTs to construct higher-quality highways and roads more rapidly and with increased safety of the workers. Using this combination, some operations have increased their production by up to 50% and slashed surveying costs by up to 75%. In addition, EDC-3 also stimulated electronic construction as an effectual tool to 1) eliminate the delays in paper-based project management; 2) execute secure, quick, and transparent document distribution, transmission, and storage; and 3) improve real-time management (Landers 2015; Leary and Walker, 2018). E-construction research reports that on average, E-construction saves inspectors 1.78 h each day and 2.75 times more data and can save contractors as much as $40,000 per year per construction project (Weisner et al., 2017). The Pennsylvania Department of Transportation (PennDOT) forecasts a yearly operating savings of $23.4 million, including $5.9 million from construction documentation (Turner-Fairbank Highway Research Center and United StatesFederal Highway Administration. Office of Infrastructure, 2017). Operating savings can be understood as the elimination of paper-based inspection paperwork and construction administration, as well as cost savings in areas such as storage and supplies. The Florida Department of Transportation (FDOT) formalized the use of a specialized software platform for project collaboration, tablets for field data collection/documentation, and formal partnerships for select contracts. To allow rapid data collection and to address the difficulties encountered in day-to-day field operations, the FDOT implemented E-construction for all construction contracts. According to the agency, a $1.1 million investment has resulted in saving $22 million in administrative processing costs every year (Torres et al., 2018).

Different domains of study have synthesized the information related to the use of E-ticketing and material tracking technology in the construction industry (Hedgepeth 2010; Newcomer 2018; Patel et al., 2019; Subramanya et al., 2020; Nipa et al., 2022); however, no study has created a vital body of knowledge relating to the use of E-ticketing in transportation projects. In highway resurfacing operations, the potential is great for automating the collection of delivery tickets and monitoring pavement temperatures, test results, inspection records, and billing. Asphalt paving is one of the areas where the inclusion of E-ticketing technology and automation may make a significant difference. The present study fills the knowledge gap of the current and future technological trends in delivering transportation projects by achieving the following objectives: 1) understand the current state of material delivery in transportation projects and develop a framework to automate/simplify the work processes, 2) identify the reasons for the lack of widespread implementation of technology, 3) develop strategies and suggest suitable technology integration to overcome the limitations, 4) employ E-ticketing technology as a tool for rendering automated inspections, billing, and record-keeping.

2 RESEARCH METHODOLOGY

The approach of systematic review is utilized to address the study's research questions. Systematic reviews are an empirical technique for minimizing bias in the identification, selection, and synthesis of study outcomes. **Figure 1** summarizes a four-step process adopted in this study to acquire up-to-date and high-quality papers and ensure a comprehensive review of E-Ticketing technology was made. The steps are 1) Analyzing the need for research and developing research questions to guide the study 2) Data collection 3) Article screening and literature review 4) Research Gaps, Future Research Opportunities. The research has focused on conducting a qualitative analysis of the previous studies' literature which involves the collection, analysis and interpretation of data that are not easily reduced to numbers. The authors have made sure all the issues are examined in detail and depth to enhance the reliability of the study.

Step 1: Analyzing the need for research and developing research questions: The research process began with developing research questions and establishing the scope and objectives of the study. It was determined that the purpose of the study was to address the problems in the highway construction material supply chain and to

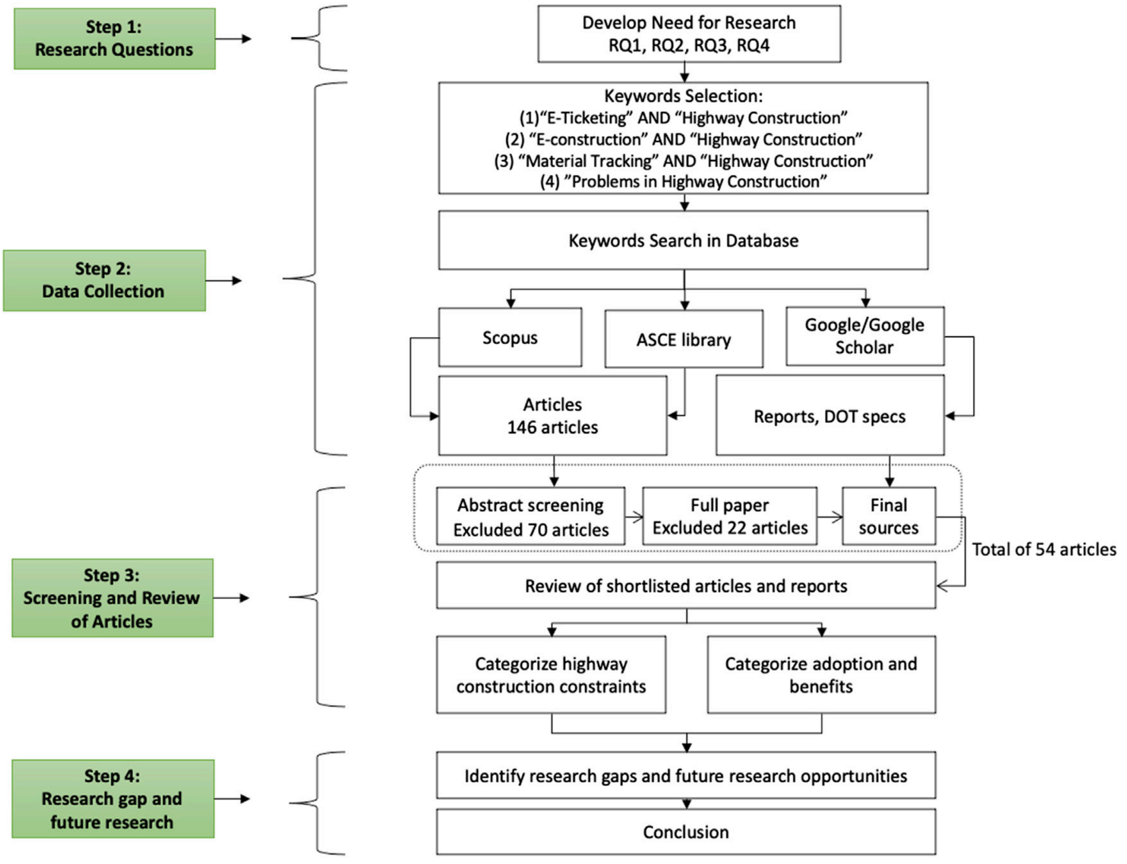

FIGURE 1 | Research methodology.

optimize the day-to-day operations of inspectors and engineers at the site by using the E-ticketing platform. Four research questions were developed to guide the study and to further analyze the technology in terms of adoption rates, benefits, and limitations. The four research questions are:

RQ1. What problems are experienced in the delivery of materials, inspection/testing records and ticket documentation in day-to-day highway construction operations?

RQ2. What are the components benefits, and adoption level of the E-ticketing system, and what strategies do state DOTs employ to increase its usage?

RQ3. What are the research-validated technologies that can be integrated with the E-ticketing platform to semi-automate processes?

RQ4. What are the key problems that are encountered in paving operations and describe the role of the person responsible for mitigating or eliminating them? How does E-ticketing and technology integration help in minimizing these problems?

Step 2: Data collection: This step entailed an iterative three-task process comprised of: 1) identifying the sources, based on keywords; 2) categorizing the sources by types, based on identifiers; and 3) repeating the tasks, using different search engines (Google Scholar, ASCE Library, Scopus). Some of the keywords used were e-construction in highways, e-ticketing, limitations in highway inspections, highway construction technology, inspection technology, document management in highway construction, material tracking in highway construction, and material supply chain in highway construction. After conducting a more narrow search of journal articles, the authors expanded the search to include book chapters, government reports, conference articles and proceedings, and undergraduate and graduate students' thesis and dissertations.

Step 3: Screening and review of literature: The collected data was originally comprised of 146 papers from selected journals. The abstracts of all 146 were rigorously reviewed and synthesized, and 70 of them were excluded from further analysis due to their lack of discussion on highway construction and E-ticketing technology. The 76 remaining articles were carefully read in their entirety, and their contributions to the research questions were analyzed. This resulted in excluding 22 more articles, leaving a database of 57 journal articles. Later, technical reports from the FHWA, state DOTs, and the National Highway Research Program (NCHRP) were added to

TABLE 1 | Total type and number of sources.

Type of source	Year range	Articles reviewed	Articles included
Journals and Books	1990–2022	120	37
Conference/Magazines/Thesis	2000–2022	26	15
Institutional Reports	2010–2022	18	13
Total Sources		164	65

capture the practical perspective. Two criteria were used in their selection: 1) the report was published based on federal research projects conducted on highway construction material supply and ticketing, and 2) the report discussed recent adoption levels and strategies utilized in the implementation and roll-out of the E-ticketing platform that were not covered in the journal articles. **Table 1** contains a list of journals, conference articles, books, and reports that were analyzed for this study, along with the year of publication and the identifiers attached to them. The documents were extensively reviewed by examining the abstracts, titles, keywords, technologies reviewed, methodologies adopted, and adoption levels.

Step 4: Research Gap, Opportunities and Conclusion: We identified the critical research gaps through the literature analysis and pointed them out in reference to the wide-scale implementation of e-Ticketing technology. Based on the research gaps, the authors have suggested three future research opportunities which will assist the DOTs, general contractors, and material vendors to integrate and reap the full benefits of this technology nationwide. Lastly, the findings and analysis of the study were summarized and interpreted into a single integrated context.

3 OVERVIEW OF HIGHWAY CONSTRUCTION

Transportation agencies are bringing the conventional, inefficient, paper-based approach of document management into the digital era by implementing E-construction technology. With the increased integration of information technology, project stakeholders may see the advantages and benefits of construction partnerships in digital project delivery. Before discussing the concept of E-ticketing, this section provides the framework and scope of this research's focus on digitization in highway construction. The following section briefly discusses the notion of digitization in the construction sector, as well as highway construction issues that are connected to and will affect E-ticketing technology acceptance and implementation.

3.1 Digitization and Computing Technology in Highway Construction

According to Cruz and Sarmento (2018), road infrastructure digitization may be divided into two categories: those that are asset-related and those that are service-related. The major focus of this research, as illustrated in **Figure 2**, is not the study of service-related computer technology since it is oriented towards supporting infrastructure. Rather, the focus is primarily on asset digitalization, which employs computing technologies in the design and construction phase. In the construction sector, computing technology is divided into two categories: 1) automation and 2) information and communications technology (ICT) (Perkinson et al., 2010). Construction automation uses computers to replace and/or improve a range of worksite activities, including surveying, equipment control, and the placement of prefabricated modules, all of which utilize GPS and sophisticated robotic systems. The use of computer systems capable of recording, organizing, storing, analyzing, exchanging, transferring, and sharing information is referred to as construction ICT. This research extensively studies E-ticketing technology, which encompasses both automation and communications technology.

3.2 Constraints and Challenges Encountered in Highway Construction

The transportation industry suffers from a wide variety of problems, including shortages in skilled labor and other types of workers, final project quality issues, document managing, cost overruns, injuries/fatalities, and schedule delays (Creedy et al., 2010; Kermanshachi et al., 2017; Wang et al., 2017; Habibi et al., 2018). The National Cooperative Highway Research Program (NCHRP) states that "DOTs are managing larger roadway systems with fewer in-house staff than they were 10 years ago." According to a study performed by Taylor and Maloney, 2013 from the year 2000–2010, state-managed highways increased 4.10% and the full-time equivalent employees dropped by 9.68% which indicates a solid workforce shortage within the 40 state DOTs on which the study was based. The majority of construction projects have cost and schedule overruns (Vidalis and Najafi 2002) that can be caused by the cost of utilities, damage resulting from weather, delays of material delivery, quality issues, and material reconciliation and result in construction expenses exceeding the budget and projects being delayed. Over the course of a project, a contractor must often satisfy a number of standards in order to provide project information and records, such as bills of materials, testing reports, inspection records, and a variety of other papers. Because the majority of construction work takes place in the field, these documents are frequently paper-based rather than electronic and must either be moved to a system, requiring re-entry of the information, or stay in a burdensome and difficult-to-retrieve paper format.

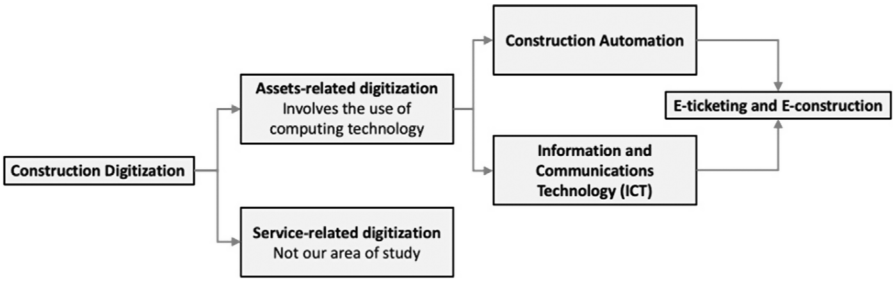

FIGURE 2 | Hierarchy of digitization in the construction industry.

FIGURE 3 | Process of material delivery adopted by TruckIT.

4E-TICKETING TECHNOLOGY OVERVIEW

An e-ticket is an electronic document that may be stored in a mobile phone or a computer as proof of confirmation, delivery, and reservations for any event or activity. Stakeholders and consumers realize numerous advantages from using E-ticketing, and many industries such as event management, airlines, public transport, and entertainment, have already fully adopted it (Smith et al., 2014; Gohil & Kumar 2019; Kuncara et al., 2021). Although some industries, of which the construction industry is one, are still using the same old-fashioned paper tickets, it is predicted that the number of industries that use E-ticketing will rise over time (Rannanjärvi and Känsälä, 2003; Sathish and Sudha 2020). As defined by the FHWA, E-Ticketing is a software platform that automates the recording and transfer of information in real-time for materials as they are moved from the plant to the site.

TruckIT is a provider that serves as an example of how E-ticketing would work for construction projects. (See **Figure 3**.) Fleets of trucks are packed with materials at the plant and weighed, and electronic tickets record the type of mix material, tonnage, and truck arrival and departure times. When the vehicle leaves the plant, it is tracked *via* geofences, which uses a global positioning system (GPS), until the materials are delivered to their destination. This real-time data is made feasible through a smartphone or computer application that assists project engineers and managers in planning for the truck's arrival. E-ticketing is commonly misunderstood in construction trucking and material delivery, as it is assumed to be just an electronic document that is used as proof of delivery to avoid chances of hazards on site faced by the inspectors and project engineers. According to Li et al., 2005 when E-ticketing is combined with GPS, a geographic information system (GIS), radio-frequency identification (RFID), and active sensors, its capabilities are greatly expanded.

4.1 Key Technologies Used in E-Ticketing

The combination of GPS and GIS technology can produce a fleet management system that traces haul routes, the earliest time of arrival (ETA), and tonnage, and can also help contractors and managers balance and match their equipment appropriately with projects (Gao and Russell, 2006). Technology has evolved during the last few decades towards automated methods of tracking and delivering items/services, and construction industry professionals have slowly tested and embraced a wide range of technology ranging from RFID, automated vehicles, GPS, advanced imaging, microchips, and drone surveying to various software apps that have decreased the duration of projects, improved productivity, decreased unwanted manual skilled labor and data entry work, paved the way to higher transparency, and promoted better documentation due to cloud-based technology (Moselhi and El-Omari, 2006; Kim & Kim 2011). The main components of an effective electronic ticketing system are depicted in **Table 2**. Barcodes are used in all sectors of operations and are clearly employed in day-to-day operations. In the construction sector, they are utilized to transform barcodes/QR codes into legible pdf texts/invoices/billing/reports. The use of radio frequency identification (RFID) for material delivery has been investigated by various scholars and is helpful in tracking goods to railway cars (Jaselskis et al., 1995; Sarac et al., 2010; Zhu et al., 2012). In the industrial and transportation industries, it has been proven to

TABLE 2 | Key technologies used in E-ticketing systems.

Technology	Description	Authors
Barcodes	The process of scanning barcodes is more accurate and faster than manually entering the code. In E-ticketing systems, dump trucks' barcodes, which are attached to the windshield, are scanned by cameras when they leave the plant and are again scanned by inspectors when they arrive at the site	Statler 2016; Navon and Shpatnitsky 2005
Radio Frequency Identification	RFI operates *via* electromagnetic signals to obtain and transmit data across multiple locations and can be used by engineers and managers to enable sensing, measuring, locating, identifying, and transmitting real-time data	Andoh et al., 2012; Nipa et al., 2022; Sardroud 2012; Wang and Shi 2005
Global Positioning System	GPS is a satellite-based navigation system that can be utilized to determine the exact position of stationary or moving objects, as it broadcasts radio signals that communicate the location, status, and time. This is a useful tool in the construction industry, as it maximizes utilization of the fleets and improves job efficiency	Newcomer et al., 2018; Song et al., 2006; Razavi and Haas, 2010
Software and User Interface	Software is revolutionizing E-ticketing technology. Many companies have interfaces that are built on an application program interface (API) so that it can be integrated with other applications and software used in the heavy civil construction and materials industry	Subramanian et al., 2020; Caballero-Gil et al., 2013

TABLE 3 | Cost and duration benefits of E-ticketing.

Category	Description	Authors
Time saving	The availability of real-time information and data reduces the processing time of quality control (QC) and quality assurance (QA) and decreases the number of stoppages and delays common in conventional paper-based project administration	Elliott 2020; Sturgill et al., 2019
Operation	One of the major perks of E-ticketing is that workers, engineers and stakeholders are able to observe and analyze actual tonnage. This helps engineers confirm that projects are being constructed per the drawings and design specifications, which results in a more cost-effective project	Newcomer, 2018; Sharma et al., 2020
Integration	The information/data/results obtained from E-ticketing can be integrated with other technologies such as network-enabled cameras, intelligent compaction, AI sensors, and remote temperature control, which decreases the total manhours and the duration of the project	Durham et al., 2018; Fuller et al., 2019

TABLE 4 | Safety benefits of E-ticketing.

Category	Description	Authors
Social Distancing	Safety is the most important reason for government entities and private companies to shift to E-ticketing during the pandemic, and the number of DOT's and STA's implementing e-ticketing is depicted in **Figure 1**. DOTs and private trucking firms are discovering that E-ticketing keeps operators, inspectors, and other employees safe and expedites daily operations	Embacher 2021; Elliott 2020
Safety	The most visible advantage of e-ticketing is reducing the number of accidents and hazards caused by vehicular traffic. Replacing human inspectors with technology eliminates the concerns about safety-related hazards that are encountered while performing inspections on high-speed and well-traveled highways	Durham et al., 2018; Patel et al., 2019; Fuller et al., 2019; Federal Highway Administration, 2018
Reduced Liability	First responders are able to act quickly in accidents and emergencies, as they are provided with the exact location and time of the accident	Newcomer et al. (2018)

enhance supply chain logistics. GPS is effective for determining the exact location of trucks, as recent developments in the technology enable it to pinpoint a location within a few millimeters. The use of software applications for running and integrating technology such as RFID, barcodes and GPS, as well as the extent to which they can render accurate data, is also exceedingly important.

4.2 Benefits of Electronic Ticketing Systems

GPS truck tracking methods and E-ticketing are commonly used by private heavy civil supply chain companies for asset management and monitoring driver performance. The technology can be especially important for guaranteeing that perishable materials, like concrete and asphalt, arrive at the

TABLE 5 | Benefits of E-ticketing for stakeholders.

Category	Description	Authors
Cloud database	Exchanging, tracking, and archiving tickets, and storing the digital data of 3-dimensional design models and other metadata enhances the value of contract documents. Archiving 3D as-built drawings can help with maintenance, operations, and asset management of future projects	Elliott 2020; Dadi et al., 2020
Real-time data	Real-time data collection reduces the number of route enquiries from customers; reveals when drivers make personal stops; enables error-free ETAs; minimizes delays in haul routes or at the manufacturing plant; and monitors the temperature for laying concrete, cumulative tonnage, waste generation, and information about line graph reports with data of percentage complete in real time	Andoh et al., 2012; Turner-Fairbank Highway Research Center and United StatesFederal Highway Administration. Office of Infrastructure, 2017
Day-to-day operations	(1) Inspectors and engineers can crosscheck their delivery supply with project specifications and can approve or reject a load while entering the test results into the E-ticketing. (2) DOTs and owners have immediate access to the quantity and cost of materials delivered and can input the information into a graph to compare the values and yield better productivity. (3) Pump operators have direct access to the types of mix and the quantity required, so can adjust their machinery. (4) Material suppliers are notified in real time whether their load is accepted and will receive appropriate testing results	Alabama department of transportation, 2019; Durham et al., 2018; Newcomer et al., 2018

right location at the exact time that they are supposed to. When it comes to tracking and controlling the quality of material while it is in transit, the key to unlocking a truck's potential is the adoption of integrated technology tools as soon as they become available. Technological innovations have revolutionized the way of living and have resulted in more resourceful and quicker ways of getting things done. **Tables 3**, **4** and **5** depict the advantages of electronic tickets over the conventional system for the trucking industry, including those realized by adding a GIS interface that tracks material location and timing (Dadi et al., 2020). The current study analyzes the impacts of adopting e-ticketing in three broad categories: cost and duration, workforce safety, and stakeholders.

4.2.1 Impact of E-Ticketing on Project Cost and Duration

The conventional paper-ticketing process for handling materials for transportation projects is inefficient and has a negative impact on the cost and duration of projects (Sturgill et al., 2019). Transitioning to digitization platforms such as E-ticketing has improved the process and has been embraced even more quickly in the midst of the coronavirus epidemic (Oberg 2021). Raw materials and equipment are key components in any construction activity and account for about half of the cost. The rate at which the raw materials and equipment fleet are used is directly proportional to the growth of the project. **Table 2** shows the impact of implementing E-ticketing on the cost and length of construction projects. Integrating new and existing technologies into the E-ticketing platform can open a wide array of opportunities in the construction material delivery and paving industry (Wang and Shi 2005; Sturgill et al., 2019). Due to the increased demand for good infrastructure, many transportation agencies and state departments are making an effort to automate the construction delivery and paving process with infrared sensors, advanced imaging, automated drone surveying and inspection, and intelligent compaction (Irizarry et al., 2013; Hu et al., 2018; Li and Liu 2018; Zhou and Gheisari 2018). Importing these novel technologies into the E-ticketing platform can render enormous benefits. Automated drones can be used in conjunction with 4D building information modelling to assess project progress and to determine geometric design model compliance and emerging technologies can be used for monitoring construction projects remotely, applying/checking end-user requirements, construction education, and team collaboration.

4.2.2 Impact of E-Ticketing on Workforce Safety

Technology applications are safer and more efficient than many conventional methods. According to a survey performed by the FWHA, more than half of the accidents in highway construction zones involve inspectors or workers being run over by the equipment fleet. The impact of implementing E-ticketing on the safety of workers and inspectors is depicted in **Table 4**.

For example, the conventional method of measuring mat temperatures with handheld guns is a waste of human resources and dangerous for the inspectors who are working in high traffic areas (Stroup-Gardiner et al., 2004; Patel et al., 2019), while the use of thermal infrared technology that is mounted on a paver provides continuous temperature readings and eliminates the problems inherent with the conventional method. The Texas Department of Transportation was the first to test this technology and introduced it in the year 2000. Other examples are the intelligent compaction technology that traces the paver and roller flow, including the temperature of the mat, and projects it onto an LED screen, and drone surveying and inspections that are beneficial for engineers or project managers who are remotely working and are handling multiple projects simultaneously (Anwar et al., 2018).

4.2.3 Impact of E-Ticketing on Stakeholder Interest

The adoption of any new technology requires an initial investment, but the benefits are many, including the elimination of lost paper tickets which helps minimize

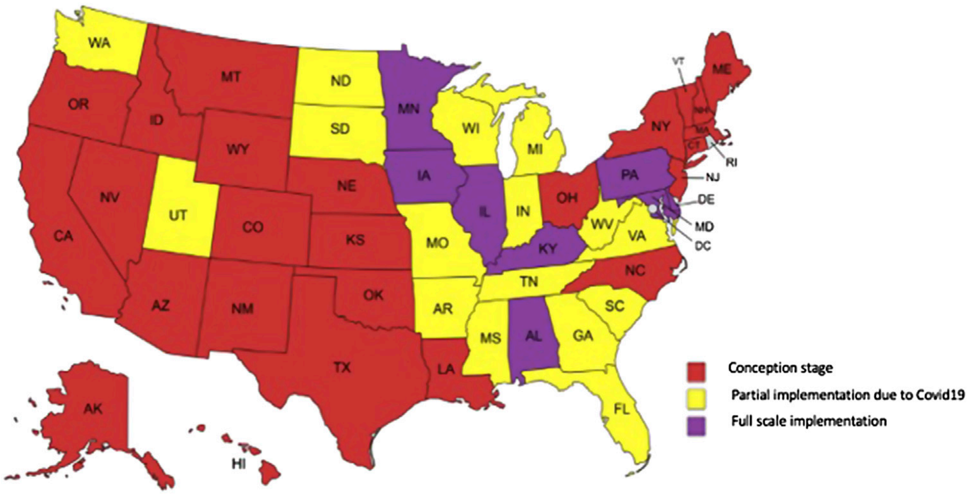

FIGURE 4 | Map depicting adoption of E-ticketing by states (USA).

TABLE 6 | Limitations of E-ticketing systems.

Limitation	Source
Static with mobile geozone, which leads to storage of inaccurate data	Sturgill et al., 2019; Embacher 2021
Issues with internet accessibility or networks at remote plant locations	Newcomer et al. (2018)
Contractors outsourcing trucks that are not equipped with responders and microchips	Sturgill et al., 2019; Embacher 2021
Standardized format of data files that are exported and imported into the online database	Weisner and Nieves (2021)
Difficult decision making related to whether to purchase the system from an outside vendor or create an in-house application	Nipa et al. (2022)
Lack of personnel who are able to adapt to the new technology and nullify the use of legacy systems	Nipa et al. (2022)
Challenges relating to bidding of E-ticketing providers, including supplemental agreements	Dadi et al. (2020)
Concerns of stakeholders relating to the privacy of stored data	Alabama department of transportation, (2019)
The need for time-consuming and intensive training on multiple E-ticketing platforms	Sturgill et al. (2019)
Stakeholders' concerns about the return on their investment	Dadi et al., 2020; Turner-Fairbank Highway Research Center and United StatesFederal Highway Administration. Office of Infrastructure, 2017

quantity disputes at the time of billing and reconciliation. Stakeholders, ranging from investors to employees and customers, reap many advantages, as shown in **Table 5**. Training is vital for all those involved, and helps the employees experience the benefits first-hand.

4.3 Limitation and Pushback in Implementation of E-Ticketing

Private companies in the United States have widely adopted the integration of E-ticketing and fleet tracking, but despite the benefits, many state transportation agencies (STA) are not willing to transition into the technology. Reasons for this include indecision of whether to purchase the system from an outside vendor or create an in-house application, lack of technological skills, and internal/external resistance to adoption of new technology, as depicted in **Table 6**. The Iowa Department of Transportation initiated the first E-ticketing pilot program in 2015, and since then, many DOTs have piloted/experimented with the technology, but few have adopted them in full scale, as they find it difficult to understand the extent of the benefits.

5 TECHNOLOGY ADOPTION BY STATE DOTS

Various DOTs have piloted the technology for asphalt/concrete paving, and this section discusses the extent to which the level of adoption has changed, the DOTs' implementation strategies, and the impact of COVID-19 on the E-ticketing platform. Numerous

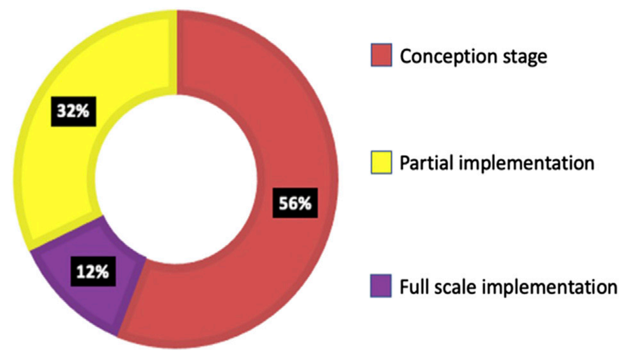

FIGURE 5 | Percentage of states implementing E-ticketing at various levels.

memorandums, letters, specifications, and DOT websites were examined to collect data on the levels of adoption rate.

5.1 Accelerated Adoption due to COVID-19

The coronavirus created a need for implementing social distancing and minimizing personal face-to-face interactions, and researchers espoused that construction logistics and material suppliers should adopt technologies to bolster social distancing (Alsharef et al., 2021; Pamidimukkala and Kermanshachi 2021). Many DOTs have pilot tested and begun implementing an electronic-ticketing system to protect their employees, as the transportation industry is deemed an essential entity and is behoved to operate safely amid lockdowns and the pandemic (Majumder and & Debasish Biswas, 2020; Ogunnusi et al., 2020; Subramanya and Kermanshachi 2021). A number of DOTs, including those in the process of developing specifications for E-ticketing, have also adopted contactless delivery standards to maintain social distancing (**Figure 4**). In response to the rising concerns of the pandemic, some E-ticketing firms, such as Alkon, Earthwave, TruckIT, RuckIT, and Libra Systems offered complimentary services and discounts during the pandemic and have realized a significant increase in demand for their products over time.

Many material suppliers are taking steps to transition from scale house operations to E-ticketing, and STAs and DOTs are issuing strict social distancing guidelines that make E-ticketing attractive to contractors (**Table 6**). In 2019, the Transportation Research Board (TRB) conducted a survey and recorded data of ten states' experiences with E-ticketing. Currently, TRB reports that since the beginning of the pandemic, 14 states have initiated pilot projects and research, 5 are in the process of implementation, and 15 more have begun working towards E-ticketing. **Figure 5** indicates the percentage of states that fully adopted E-ticketing before the pandemic and the percentage that have partially implemented it due to the rising urgency of the pandemic and the need for social distancing. The coronavirus has led to more than 32% of DOTs deploying specifications to general contractors and software vendors and implementing specifications, including E-ticketing platforms, to keep their employees safe by optimizing the benefits of social distancing. Departments and agencies have begun initiating pilot tests, and a new task force, the National Construction Materials E-ticketing Task Force, was launched by the federal government to create partnerships between state DOTs, contractors, and software vendors who are committed to the digitalization of the construction material supply chain.

The task force mission is to increase workforce productivity, develop sustainable technology, and improve safety among inspectors and engineers. The task force, which was launched on 21 October 2021, reports that 42 states have collaborated and partnered with them to facilitate digital transformation within the highway construction industry (Karthick et al., 2021). The main motive of the collaboration is to eliminate the use of paper tickets for asphalt, ready-mix concrete, and aggregates for all transportation infrastructure projects. Various departments have issued memorandums, specifications, reports, and requirements, and the strategies adopted by various state DOTs before and during the pandemic are shown in **Table 7**.

6 DISCUSSION AND LESSONS LEARNED

6.1 COVID-19 and Safety

Globally, the construction industry must keep pace with technological advancements to provide cost-effective, safe, and quality-proven products and services. The COVID-19 pandemic accelerated the growth of E-ticketing platforms nationally and set the stage for advancement and innovation in the transportation construction industry. Prior to the pandemic, many DOTs and private firms were piloting E-ticketing projects, but as the proverb goes, "Necessity is the mother of all invention," and the pandemic served as a catalyst for accelerating the adoption of E-ticketing by the construction transportation industry. E-tickets have many safety-related benefits, including eliminating vehicular accidents and dangers associated with inspections and climbing on equipment.

6.2 E-Ticketing and Integration

When the platform is combined with fleet management, it increases productivity and reduces expenses. The technologies that enhance the e-ticketing platform (GPS, GIS, barcodes, fleet management, and RFID) have been proven beneficial through pilot tests, research, and application. Furthermore, when the platform is integrated with thermal profilers, IC-enabled pavers, drone surveying, and advanced imaging, the applications and the usage of the platform increase exponentially. Hand-held infrared thermal cameras/guns traditionally used by highway construction inspectors to verify adequate pavement temperatures and to locate isolated regions in the matting can be replaced with thermal profilers positioned on the pavers that track the temperature of the whole mat in real-time. An infrared temperature monitoring device may be fitted at the rear of the paver to provide a continuous record of mat temperatures throughout the project. Intelligent compaction (IC) technology can be used to increase quality control during the compaction phase of paving projects and can be integrated into the e-ticketing platform to obtain live feed from remote locations. Technologies that can be integrated into the E-ticketing platform can simplify day-to-day operations by automating them, and various responsibilities and operations performed during paving operations

TABLE 7 | State-wide implementation of guidelines and policies.

States	Description
Kentucky	Kentucky used E-ticketing systems provided by Fleetwatcher on two of their pilot projects The Transportation Cabinet of Kentucky stopped accepting paper tickets DOT's established and distributed strict guidelines, procedures, and memos
Indiana	The Transportation Department suspended its requirement for paper tickets during the COVID-19 pandemic and empowered its general contractors and clients to use E-ticketing systems Guidelines and memos issued by the Indiana Department of Transportation (INDOT) suspended until further notice the requirement of paper tickets for delivery of construction materials
Georgia	Before COVID-19, the Georgia Department of Transportation (GDOT) initiated 5–7 E-ticketing pilot projects. Recently, they said that they will utilize a contactless ticketing system The DOT is providing contractors with three options: using conventional paper tickets, using contactless tickets such as emails, or using E-ticketing systems
Michigan	Due to the ongoing pandemic, the Michigan Department of Transportation and the FHWA partnered to generate a revised material ticket method for construction projects Contractors and engineers are authorized to transmit an electronic copy of tickets (pictures, scanned documents, etc.) to the person appointed by the engineer when the truck is dispatched or discharged
Mississippi	All contractors or suppliers who are using an e-ticketing system provided by a private firm can cease delivering conventional paper tickets until the system chosen is advocated by the department and the relevant workers have been trained on the new software and technology Contractors not utilizing or still in the process of adopting E-ticketing should send a photo/scanned copy of a printed conventional ticket and transfer it to an internet-enabled device with a 4G connection bandwidth
Florida	E-ticketing systems must provide the engineer or contractors with real-time monitoring of asphalt truckload ticket information The Florida Department of Transportation (FDOT) specifications state that inspectors must be provided with a way to gather inspection and test summaries *via* Android or iPhone apps, online portals, or other feasible means that are acceptable
Iowa	Iowa piloted projects from 2015 to 2019, and the Iowa DOT uses Command Alkon's CONNEX Jobsite as their E-ticketing system The firm Alkon produced 9,000 tickets in 1 year in an effort to minimize the duplication and printing process and to eliminate paper tickets
Pennsylvania	Contractors or project engineers are required to maintain a GPS management system that is either consolidated into or separate from the electronic ticketing system Pennsylvania DOT's memo states that, "Producers capable of E-ticketing may elect to provide delivery tickets in this manner at no additional cost."

can be automated/simplified with the help of E-ticketing and other emerging technologies. **Table 8** depicts the benefits of full-scale implementation of E-ticketing technology, including solving workforce shortages, monitoring quality issues, and reducing cost/schedule overruns in transportation infrastructure projects. It is important to note that E-ticketing systems are not used solely for the purpose of documentation and safety, but also as an efficient tool for producing and generating automated inspections, automated tracking, real-time data, cost deductions, and record-keeping while maintaining social distancing, as necessary.

6.3 Adoption and Technology Implementation:

All project stakeholders can benefit from using E-ticketing software, as it improves communication and operations while expediting project delivery. As of January 2021, 12% of the state DOTs (six states) had achieved full fledge implementation of E-ticketing policies and guidelines. In response to restrictions mandated by the coronavirus, 32% of the state DOTs implemented temporary and/or partial E-ticketing; 56% (29 states) of the DOTs are still in the conception stage. According to a report generated by the National Construction Materials E-ticketing Task Force in October 2021, 42 states' DOTs have partnered with them to digitize the material delivery process in transportation infrastructure projects. There has also been a significant rise in the percentage of states who are utilizing e-ticketing technology. Early in this study, it was found that DOT regulations drastically vary from state-to-state, which impacts whether or how rapidly they adopt new technology. As E-ticketing is more widely adopted, inspectors and engineers will need to be trained on numerous software platforms, and rivalry will accelerate among the stakeholders throughout the contracting and pre-construction phases. Quality issues are also a possibility if inspectors have not received adequate training prior to the deployment of the E-ticketing systems.

TABLE 8 | Technologies for automating/simplifying work processes.

Responsibility	Operations performed	Technology to simplify the process
Inspector	Approve/reject the material	E-ticketing
Inspector	Ticket collection and documentation	E-ticketing
Project engineer	Monitoring truck arrival/dispatch timing	E-ticketing
Project engineer	Checking project/pour completion	E-ticketing
Project engineer	Material reconciliation and billing	E-ticketing
All stakeholders	Social distancing when required	E-ticketing
Inspector	Checking mat temperature during pour	E-ticketing and IR enabled devices
Inspector	Check conformance with project specification	E-ticketing, drone inspection (UAV) and advanced imaging
Inspector	Checking compaction level during paving	E-ticketing and intelligent compaction
All stakeholders	Social distancing when required	E-ticketing, drone inspection (UAV), intelligent compaction and IR-enabled devices

7 RESEARCH GAPS

Although the literature contributes information on the benefits of implementing the E-ticketing platform, the following gaps need to be filled by future research.

1. As is evident from **Table 7**, the wide variety of ways that different DOTs use E-ticketing make it challenging to understand its benefits. In addition, the four main stakeholders (state DOT, general contractor, material vendor, and inspection agencies) utilize it in different ways, according to their areas of responsibility. Both of these areas need to be investigated so that a framework can be developed for E-ticketing that can be applicable to the variety of ways in which it is used.
2. Most of the methodologies described in the literature are state-of-the-art reviews and case studies, but the extent to which the technology saves time and cost in paving operations has not yet been researched.
3. The overlapping features of E-ticketing, E-inspections, and fleet management have not been addressed in the research, despite their resulting in delays in their implementation and complicating data storage and integration.

8 FUTURE RESEARCH OPPORTUNITIES

An extensive review of relevant literature and data revealed a need for more research on three key topics that are linked to the utilization and implementation of E-ticketing platforms:

1. An analysis of the return on the investment (ROI) and cost benefits of using E-ticketing applications should be conducted and tailor-made for each type of stakeholder (state DOT, material vendor, general contractor, inspection agency) who is considering investing in the technology.
2. Information should be collected through survey questionnaires and interviews with stakeholders on the challenges that they encounter as they strive to implement E-ticketing so that innovative solutions can be developed, and a framework can be built to foster mandating the use of the E-ticketing platform.
3. Future studies should consider integrating material testing and inspection test results into a single E-ticketing platform. The massive amount of metadata that is available from all the digital information stored in a single database platform will provide open access to the daily operations of paving and trucking.

9 CONCLUSION

The inherent delays, challenges, and inefficiencies of paper-based ticketing were thoroughly investigated and are set forth in this paper. Delays in day-to-day activities may be greatly reduced and projects can be completed on time and within budget by training personnel how to use E-ticketing. Safety issues also can be resolved by E-ticketing, as it minimizes vehicular accidents that are all too common in highway construction and can help in maintaining social distancing. Analysis of the adoption levels of DOTs reveals that from January 2021 to October 2021, many state DOTs began pilot testing E-ticketing software. This study suggests four things that will assist stakeholders in transitioning from pilot tests to full-scale implementation. First, since the construction industry is deemed an essential business that should operate during lockdowns, it must stay aware of warning signs of the next pandemic and have technologies that enable remote working and automate unskilled processes. Researchers, practitioners, stakeholders, and governments are investing extensively in technologies to eliminate the use of paper tickets and improve sustainability in the construction industry. The accelerated deployment of e-ticketing technology due to the pandemic has created different levels of implementation and guidelines that vary drastically from state to state. Due to the partial implementation of this platform during the peak COVID-19 period, several state DOTs have not explored the full potential of the platform and have only emailed image/pdf versions of tickets. This has created a widespread misunderstanding of the full potential of the platform and its abilities to simplify and automate daily operating tasks. Secondly, the DOTs who have implemented guidelines only from the perspective of social distancing should also explore the other possible advantages of E-ticketing and should begin their pilot projects.

E-ticketing can alleviate many of the industry's challenges by helping those struggling with declining workforces, cost overruns, and schedule delays. Thirdly, the integrated platform will enable departments to utilize highly skilled staff and inspectors as a centralized resource that can monitor multiple highway projects efficiently without travelling. Combining E-ticketing with other sophisticated technologies maximizes the platform's potential and offers several significant advantages. It delays the retirement of personnel and entices retirees back to work part-time by providing rewarding employment in a pleasant, safe, and flexible work environment, and results in vast amounts of project information such as contract cost, contract duration, actual cost, actual duration, cumulative wastage, inspection checklist data, type of material, project size, number of trucks, number of inspectors, etc. that were previously difficult to assemble. Lastly, the vast amount of metadata can be used to produce predictive models related to cost optimization and quality standards. If all construction data, from contract to material delivery to project completion, is fed into a single database, it will aid in further analysis of the raw data, produce appropriate tender prices, and establish a baseline for transportation projects, thereby reducing cost overruns and schedule delays.

AUTHOR CONTRIBUTIONS

KS, SK, and AP contributed to the conception and design of the study. KS and AP collected the data and organized the database. KS performed the interpretive analysis. KS wrote the first draft of the manuscript. SK supervised the study. All authors contributed to manuscript revision, read, and approved the submitted version.

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