Development of Multi Criteria Decision-Making Model to Evaluate the Adoption Effectiveness of Electronic Ticketing (e-Ticketing) in Highway Construction Projects

by

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DEDICATION

My parents

Balasubramanya Dharmaiah and Sandhya Subramanya

For their endless and unconditional love!

My sister and brother-in-law

Bhargavi Subramanya and Shibalik Mohapatra

For their continued support and encouragement!

My friends

Pramith Jain, Nishanth Sangameshwar and Vandana Holalu

For believing in me even when I doubted myself!

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NOMENCLATURE

FHWA	Federal Highway Administration
DOT	Department of Transportation
GPS	Global Positioning System
ICT	Information and Communications Technology
GIS	Geographic Information System
RFID	Radio-frequency identification
ETA	Estimated Time of Arrival
TRB	Transportation Research Board
API	Application Programming Interface
IRB	Institutional Review Boards
ROI	Return on Investment
ASCE	American Society of Civil Engineers
RII	Relative Importance Index
ISI	Importance Severity Index
FSE	Fuzzy Synthetic Evaluation
CEI	Critical Effectiveness Indicators
MF	Membership Function
EEI	e-Ticketing Effectiveness Index

ABSTRACT

DEVELOPMENT OF MULTI CRITERIA DECISION-MAKING MODEL TO EVALUATE THE ADOPTION EFFECTIVENESS OF ELECTRONIC TICKETING (E-TICKETING) IN HIGHWAY CONSTRUCTION PROJECTS

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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. State departments of transportation (DOTs) are constructing and managing more highway projects than ever before despite limited funds and a shortage of inspectors. The construction of highway infrastructure has devoted significant resources towards e-Construction to reduce the paperwork and automate the tasks in daily operations. Electronic Ticketing (e-Ticketing) is one such component of e-Construction that aids in the digital transfer of material tickets such as asphalt and concrete which accounts for more than fifty per cent of construction costs. Despite the benefits of e-Ticketing, many state departments and agencies are unwilling to transition into this technology. The technology has been pilot tested by several states since the beginning of 2013 and has been disbanded for various reasons. A few DOTs and general contractors have implemented e-Ticketing technology to increase their workforce productivity and efficiency, but the majority are still using conventional paper methods because they do not fully comprehend the benefits of the technology. No studies have identified the cause of the delay in the implementation process, developed a framework to comprehend the platform's full potential, quantified savings, and suggested strategies for overcoming limitations. Therefore, this study aims to (1) Indicate inefficiencies in the conventional paper

ticketing framework and identify suitable technology to overcome the inefficiencies. (2) Identify benefits, quantify the reduction in inspection staff and time savings incurred by implementing e-Ticketing technology. (3) Develop a multi-criteria decision-making model for implementation of e-Ticketing platform in the perspective of state DOTs and general contractors. (4) Identify and rank the major limitations in the process of implementing e-Ticketing technology and suggest suitable strategies to overcome them.

To achieve the study's objective, the changes in technological trends in highway construction relating to material tracking, inspection, and digitization are qualitatively analyzed using meta-synthesis and interpretative analytical techniques. The review section is followed by a semi-structured interview of participants who work for the DOTs, general contractors, material vendors, and software vendors. The inductive thematic analysis approach was employed to analyze the interview transcripts using MAXQDA software. Later a survey was conducted to determine highway construction stakeholders' opinions on critical readiness indicators, benefits, adoption levels and future integration of e-Ticketing technology. Based on the survey responses collected from 20 state DOTs, the study categorized the critical effectiveness indicators into 3 categories and ranked the operational challenges using the Relative Importance Index. The study analyses the critical effectiveness indicators (CEIs) of e-Ticketing technology and presents a fuzzy index-based decision-making model for evaluating the adoption priorities.

The findings from the literature review suggest that the implementation process and regulations of an e-Ticketing platform vary drastically from state to state and established 17 indicators which directly influence the adoption and readiness of e-Ticketing implementation. A framework comprising inefficiencies in conventional ticketing, key reasons for delayed implementations, and strategies to overcome the obstacles was derived from a thorough analysis of interview transcripts. A comparison was made between the required number of inspectors prior to and after the implementation of e-Ticketing, and it was found that projects requiring multiple inspectors could reduce their workforce by 25% by implementing e-Ticketing. The study's findings will assist practitioners with an assessment tool to gain insights relating to priority levels in implementing the e-Ticketing technology.

The e-Ticketing Effectiveness Index (EEI) model can provide the state DOTs and general contractors with a decision-making assessment tool which will facilitate in widespread adoption of e-Ticketing technology. The findings will also help DOT decision-makers and engineers to build a standard e-Ticketing platform, implement rules and guidelines, reduce project costs, provide initial funding, execute pilot testing, improve inspector safety, and complete projects in a timely and efficient manner.

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CHAPTER 1

INTRODUCTION

1.1. Background

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 (Cruz and Sarmento 2018; Alaloul et al., 2018; Kermanshachi et al., 2018; Safapour et al., 2022). 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; Subramanya et al., 2022a; Jafari et al., 2021). The construction sector is well-known for its quality, safety, and budget issues that impact a project's operating life, and nonconformance quality issues may result in penalties that impose cost and schedule overruns that are associated with reworks (Haupt and Whiteman 2004).

FHWA defines e-construction as, ‘‘the creation, review, approval, distribution, and storage of highway construction documents in a paperless environment’’ . E-construction is an umbrella term that refers to a broad variety of technologies and procedures that attempt to enhance the productivity and safety of the construction industry by eliminating the need to manually handle and keep track of paper paperwork. e-Ticketing is an example of a collaborative electronic construction technology that has shown promising outcomes in the business. Through the use of paperless administration and workflow, e-Ticketing is able to solve the issues that were caused by the inefficient traditional approach of paper tickets. These issues included an unsafe working environment for workers and inspectors, the entry of data manually, and a delay in billing and payment. An e-ticket is an electronic document that may be stored on a mobile phone or a computer as proof of confirmation, delivery, and reservations for any event or activity.

Stakeholders and consumers realize numerous advantages of using e-Ticketing, and many industries such as event management, airlines, public transport, and entertainment, have already fully adopted it (Gohil & Kumar 2019; Smith et al., 2014; Kuncara et al., 2021; Subramanya et al., 2022b). Although there is solid evidence of the benefits of using this technology, the majority of the state DOTs have not implemented this platform for a variety of reasons. Some of the DOTs have pilot-tested and disbanded the technology due to its high investment cost. Different domains of study have synthesized the information related to the use of e-Ticketing and material tracking technology in the highway construction industry (Hedgepeth 2010; Newcomer 2018; Sharma el al., 2020; Patel et al., 2019); however, no study has created a vital body of knowledge relating to the time savings, increase in productivity of inspectors and cost savings incurred due to the implementation of e-Ticketing technology. As a result, the existing literature lacks to quantify the benefits of implementing the technology which has led to a slowdown in the implementation process. A decision making model is required for the state DOTs to fully understand the potential of technology implementation and an assessment tool to categorize their implementation priority.

1.2. Problem statement

The highway construction industry suffers from a wide variety of problems, including shortages of inspectors and engineers, final project quality issues, document managing, cost overruns, injuries/fatalities, and schedule delays (Creedy et al., 2010; Anderson et al., 2016; Kermanshachi et al., 2017, Habibi et al., 2018; Wang et al., 2017). 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, state-managed highways increased by 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. Factors such as lower pay, budget cuts, and a booming private industry drive people away from working in the public sector (Kermanshachi et al., 2020; Taghinezhad et al., 2021). Qualified personnel are leaving DOTs because of retirement and are being replaced by less-experienced personnel who are taking on more responsibility earlier in their careers. In fact, some DOTs are not filling the positions at all.

Furthermore, producing, sorting, recording, and archiving paper tickets is a costly and time-consuming task for both state DOTs and contractors (Sadasivam and Sturgill 2021). These documents, which include bills of materials as well as testing reports, inspection records, and a variety of other documents, are commonly required by the contractor and the owner's representatives during a project. Documents that need to be transferred to a system, necessitating re-entry of information, or remain in a cumbersome and difficult-to-access paper format are common in the construction industry, where most of the work is done on the job site. At paving projects, the practice of physically collecting delivery truck load tickets exposes inspectors to several safety dangers. Highway construction inspectors have to deal with a variety of potentially dangerous scenarios on the job site, from strolling alongside traffic to getting on board trucks to get tickets. Handing off and entering data through paper tickets is a time-consuming and resource-intensive process that necessitates several "touchpoints" along the way. The paper-based technique lacks traceability for materials, and the data are not as useful in the long term as they could be if they were digital. It's not uncommon for tickets to be lost or damaged which may result in delayed billing and waste of considerable time/resources. Illegible data on paper tickets is one more concern as most of the asphalt plant owners are still using DOT matrix printers with carbon copies. The DOTs in some scenarios have specific administrative staff scan each individual paper ticket into the document management software which is time-consuming and irrational work in this era of technological advancements.

1.3. Research Objectives

The study aims to extensively evaluate the utilization of e-Ticketing technology and develop a multicriteria decision making tool which will help all state DOTs to implement the technology effectively. To fulfil the aim of the study, the following objectives were formulated.

1. Identify inefficiencies in the conventional paper ticketing framework and suitable technology to overcome the inefficiencies.
2. Identify benefits, quantify the reduction in inspection staff and time savings incurred by implementing e-Ticketing technology.
3. Identify and rank the major limitations in the process of implementing e-Ticketing technology and suggest suitable strategies to overcome them.
4. Develop a multi-criteria decision-making model for implementation of e-Ticketing platform in the perspective of state DOTs and general contractors.

1.4. Dissertation Organization

Chapter 1 consists of the research background, problem statement and research objective and purpose of the study. Chapter 2 presents a paper that describes an overview of the benefits, challenges and adoption of the e-Ticketing platform by the various state department of transportation. It also discusses the strategies adopted by states during the time of peak Covid-19. Chapter 3 presents a paper that analyses the causes of delay in the implementation, and misconceptions in the platform and provides suitable strategies for the state DOTs to overcome the challenges. The study involves a semi-structured interview with 13 industry professionals who are the key stakeholders of the e-Ticketing platform. Chapter 4 addresses how the implementation of the e-Ticketing platform will help in minimizing the workforce shortage of inspectors in highway construction. The findings of this study have quantified the reduction in inspection staff through technology adoption. Chapter 5 identifies the 7 critical limitations using survey responses which are hindering the deployment of e-Ticketing technology and suggests key strategies to overcome the challenges. Chapter 6 extensively analysis the benefits of implementing e-Ticketing technology and ranks the priority of emerging technology integration with e-Ticketing. Chapter 7 ranks the operational and organizational challenges in highway ticketing process using the relative importance index and denotes the significance of e-Ticketing technology in overcoming the challenges. Chapter 8 describes a paper that shows the development of a multi-criteria decision-making model for the adoption of e-Ticketing using a fuzzy index. The paper also has an assessment tool for practitioners to understand the implementation priority and readiness. Chapter 9 covers the conclusion, limitations and recommendation for future work of the study.

CHAPTER 2

EVALUATION OF E-TICKETING TECHNOLOGY IN CONSTRUCTION OF HIGHWAY PROJECTS: A SYSTEMATIC REVIEW OF ADOPTION LEVELS, BENEFITS, LIMITATIONS AND STRATEGIES

Below is a published paper (Chapter 2).

2.1. Abstract

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.

2.2. 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 (Cruz and Sarmento 2018; Alaloul et al., 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. 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. 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; FHWA 2018). E-construction research reports that on average, E-construction saves inspectors 1.78 hours 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 (Brinckerhoff 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 (Nipa et al., 2019; Hedgepeth 2010; Newcomer 2018; Sharma el al., 2020; Patel et al., 2019); 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.

2.3. 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’s outcomes. Figure 2.1 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.

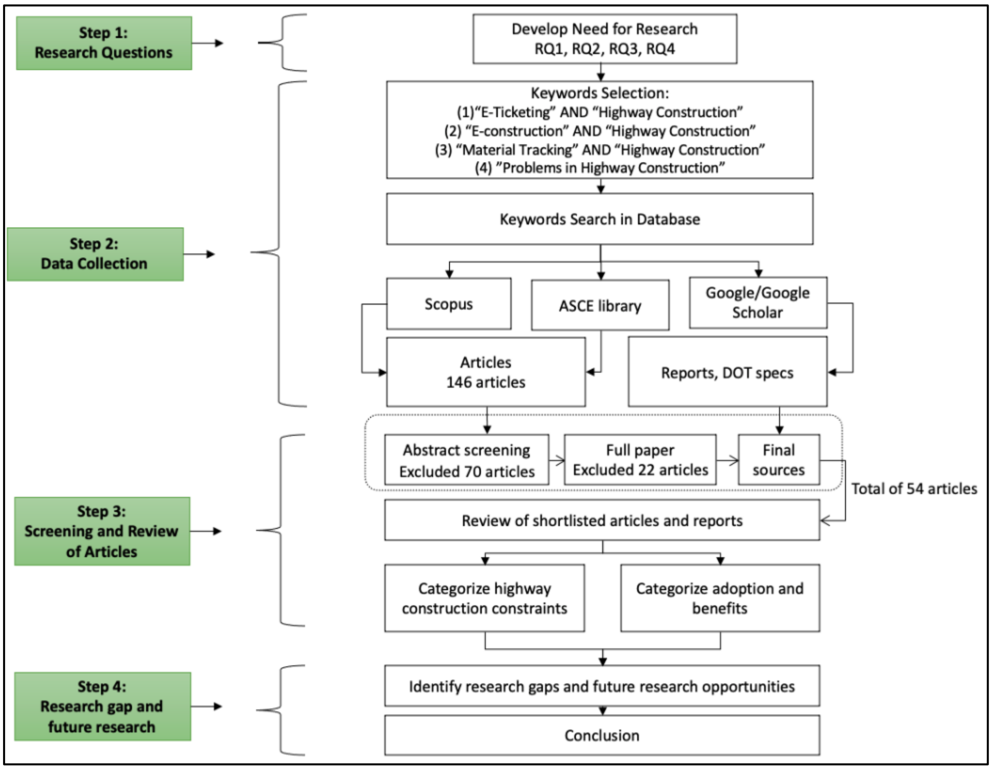

Figure 0-1. Research methodology

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 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. Identify research-validated technologies that can be integrated with the e-Ticketing platform to semi-automate processes.

RQ4. Identify the key problems that are encountered in paving operations and describe the role of the person responsible for mitigating or eliminating them. Describe how e-Ticketing and technology integration will help minimize 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.

Step3: 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 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 2.1 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.

Table 0-1. 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**

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.

2.4. 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.

2.4.1. 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 2.2, 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.

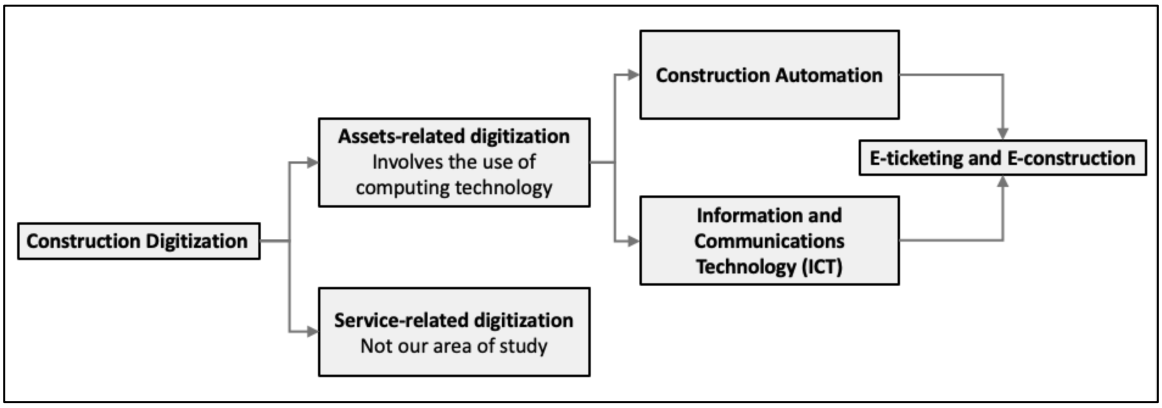

Figure 0-2. Hierarchy of digitization in the construction industry

2.4.2. 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, Habibi et al., 2018; Wang et al., 2017). 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 from the year 2000 to 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.

2.5. e-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 (Gohil & Kumar 2019; Smith et al., 2014; 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 et al., 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 2.3.) 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., when e-Ticketing is combined with GPS, a geographic information system (GIS), radio-frequency identification (RFID), and active sensors, its capabilities are greatly expanded.

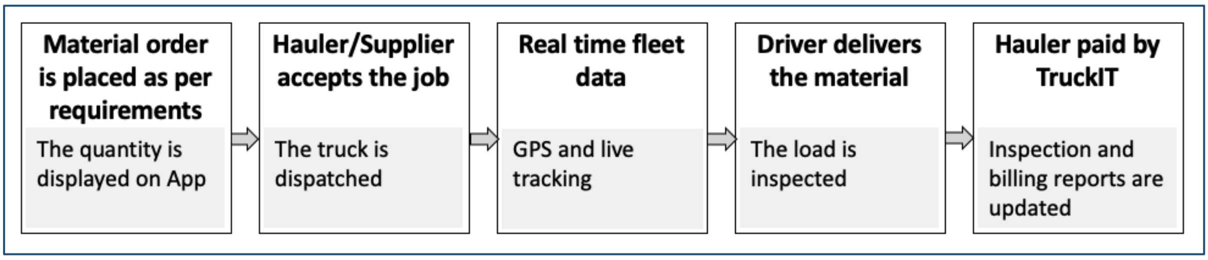

Figure 0-3. Process of material delivery adopted by TruckIT

2.5.1. 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 Walters 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 (Kim & Kim 2011; Moselhi and Omari 2006). The main components of an effective electronic ticketing system are depicted in Table 2.2. 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; Zhu et al., 2012; Sarac et al., 2010). In the industrial and transportation industries, it has been proven to 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.

Table 0-2. 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 and Kermanshachi 2019; 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.

2.5.2. 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 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 2.3, 2.4 and 2.5 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.

Table 0-3. 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.	Elliot 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 0-4. 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 Fig 1. DOTs and private trucking firms are discovering that e-Ticketing keeps operators, inspectors, and other employees safe and expedites daily operations.	Embacher 2021; Elliot 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-	Durham et al., 2018; Patel et al., 2019; Fuller et al., 2019; FHWA 2018

	related hazards that are encountered while performing inspections on high-speed and well-traveled highways.	
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., 2019

Table 0-5. 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.	Elliot 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; Brinckerhoff 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.	ALDOT 2019; Durham et al., 2018; Newcomer et al., 2019

2.5.2.1. 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 2.2 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; Li and Liu 2019; Hu et al., 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.

2.5.2.2. Impact of e-Ticketing on Workforce Safety

Technology applications are safer and more efficient than many conventional methods. Figure 2.4 compares the view from the driver's seat of a truck with a ground view of an inspector who is of average height and reveals that the driver in the truck has zero visibility of the inspector. 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 2.4.

Figure 0-4. Driver's view of inspector/worker (Source: Alabama Department of Transportation Pilot Report, 2019)

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 (Patel et al., 2019; Stroup-Gardiner et al., 2004), 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).

2.5.2.3. 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 quantity disputes at the time of billing and reconciliation. Stakeholders, ranging from investors to employees and customers, reap many advantages, as shown in Table 2.5. Training is vital for all those involved, and helps the employees experience the benefits first-hand.

2.5.3. 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 2.6. 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.

Table 0-6. 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., 2019
Contractors outsourcing trucks that are not equipped with responders and microchips	Sturgil 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 and Kermanshachi 2019
Lack of personnel who are able to adapt to the new technology and nullify the use of legacy systems	Nipa and Kermanshachi 2019
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	ALDOT Annual Report 2019
The need for time-consuming and intensive training on multiple e-Ticketing platforms	Sturgil et al., 2019
Stakeholders' concerns about the return on their investment	Dadi et al., 2020; Brinckerhoff 2017

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

2.6.1. 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 (Subramanya and Kermanshachi 2021; Majumder et al., 2020; Ogunnusi et al., 2020). 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 2.5). 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.

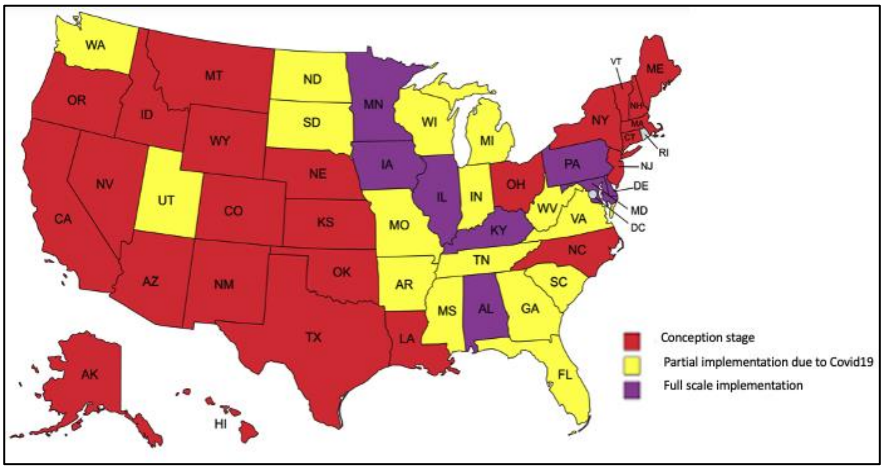

Figure 0-5. Map depicting adoption of e-Ticketing by states (USA)

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 2.6). 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 6 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.

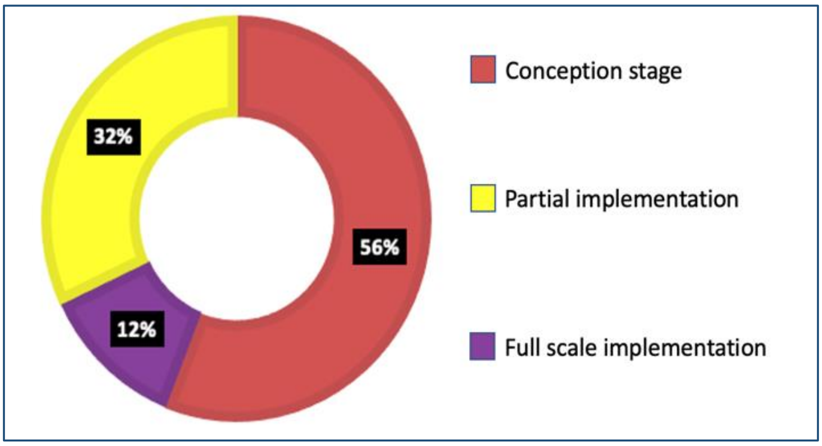

Figure 0-6. Percentage of states implementing e-Ticketing at various levels

2.7. Discussion and Lessons Learned

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. 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 can be automated/simplified with the help of e-Ticketing and other emerging technologies. Table 2.7 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. 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 (6 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 0-7. 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 9000 tickets in one 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."

2.8. 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 2.8, 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.

Table 0-8. 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

2.9. 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.

2.10. 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 on 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.

CHAPTER 3

DIGITIZING MATERIAL DELIVERY AND DOCUMENTATION IN HIGHWAY CONSTRUCTION USING E-TICKETING TECHNOLOGY: A QUALITATIVE SEMI-STRUCTURED INTERVIEW

Below is a published paper (Chapter 3).

3.1. Abstract

The construction of highway infrastructure has devoted significant resources towards e-Construction to reduce the paperwork and automate the tasks in daily operations. e-Ticketing is one such component of e-Construction that aids in the digital transfer of material tickets such as asphalt and concrete which accounts for more than fifty per cent of construction costs. The technology has been pilot tested by several states since the beginning of 2013 and has been disbanded for various reasons. The present study discusses previous literature findings in the first section relating to the utilization and implementation of the e-Ticketing platform. The review section is followed by a semi-structured interview of participants who work for the state department of transportation (DOT), contractor, material vendor, and software vendor. The inductive thematic analysis approach was utilized to analyze the interview transcripts. The analysis led to the identification of six major themes: (1) traditional ticketing process; (2) Covid-19 and social distancing; (3) e-Ticketing and fleet management; (4) adoption level by state DOTs; (5) overview of the benefits; and (6) limitations. The study's findings are related to the reason for delay and misconceptions in the implementation of the e-Ticketing platform. After a careful analysis of previous literature, interview transcripts and interpreted results, the authors have drawn key strategies for practitioners to adopt and re-define the e-Ticketing technology. The findings of this study will help DOT decision-makers and engineers to build a standard e-Ticketing platform, implement rules and guidelines, reduce project costs, provide

initial funding, execute pilot testing, improve inspector safety, and complete projects in a timely and efficient manner.

Keywords: e-Ticketing, Highway, DOT, Covid-19, e-Construction.

3.2. Introduction

In the development of transportation infrastructure projects, digitalization has encountered major setbacks. Most industries, including manufacturing, entertainment, and services, are developing solutions in response to quality, safety, and production concerns, resulting in significant performance and quality benefits (Holt et al., 2015). The construction industry is well-known for its quality, safety, and budget difficulties that affect the working life of a project, and nonconformance quality issues may result in fines that impose cost and schedule overruns connected with reworks (Haupt and Whiteman 2004; Safapour and Kermanshachi 2021). Since the 1990s, academics have examined methods to reduce the administrative labor necessary for construction field documentation by leveraging mobile technologies (Kim et al., 2016). The construction business has long experienced implementation difficulties with technology (Bossink 2004). There are legal, regulatory, institutional, technological, and economic obstacles to the digitization of transportation projects, despite the fact that digitalization can have significant effects on road building. Governments have made enormous investments in developing and improving road networks, as roads are an essential component of transportation systems, and digitization is opening the way for significant changes in how infrastructure is constructed, operated, and funded, with far-reaching ramifications throughout the lifespan of a project (Cruz and Sarmento 2018; Alaloul et al., 2018). E-construction saves inspectors an average of 1.78 hours per day and 2.75 times the amount of data and may save contractors up to $40,000 per construction project each year (Weisner et al., 2017). The Pennsylvania Department of Transportation (PennDOT) estimates annual operational savings of $23.4 million, including $5.9 million in construction documentation savings (Brinckerhoff

2017). Examples of operational savings include the elimination of paper-based inspection documentation and construction administration, as well as cost reductions in storage and supplies.

When asphalt or concrete are transported from a manufacturing facility or supplier yard to a building site or storage facility, they may be tracked in real-time using e-Ticketing, which is now available on the market. An electronic or digital format is used in this process to record and preserve material information such as the quantities that have been produced and the locations from where they have been delivered (Patel et al., 2019, Subramanya and Kermanshachi 2022). Material verification and real-time operational decisions are often made using mobile devices and data that is sent to a server for rapid use by many stakeholders. Material data management and integration into information systems for acceptance, payment, and source documentation are made easier using electronic methods (Rouhanizadeh and Kermanshachi 2020; Subramanya et al., 2022c). One of the areas where the use of e-Ticketing technology and automation might make a huge difference is asphalt paving. By addressing the following goals, the current study bridges the information gap on current and future technical developments in transportation project delivery. This study focuses on how e-Ticketing technology might alleviate issues pertaining to day-to-day operational inefficiencies, safety-related accidents, workforce shortages, quality issues, and social distancing encountered in transportation projects by conducting semi-structured interview sessions. The participants for the interview session were recruited from various state 9 state DOTs. The study also includes the perception of general contractors, material vendors and software providers which played a crucial role in understanding the limitations. e-Ticketing technology, on the other hand, has the potential to improve quality while simultaneously reducing cost overruns and time delays. Despite the obvious advantages of electronic ticketing, a significant number of state departments and agencies are resistant to adopting this new technology. The goals of this research are to (1) identify possible roadblocks to the implementation of electronic ticketing; (2) establish the acceptance rate of state agencies and departments; and (3) analyze the advantages of adopting an electronic ticketing platform. The study has also suggested key strategies for the stakeholders in highway construction to overcome the major limitations during the pilot testing and implementation phase. The findings of this study will help DOT decision-makers and engineers to build a standard e-Ticketing platform, implement rules and guidelines, reduce project costs, provide initial funding, execute pilot testing, improve inspector safety, and complete projects in a timely and efficient manner.

3.3. Literature Review

3.3.1. E-construction and Digitalization

In the digital age, transportation agencies are using E-construction technology to move away from the inefficient, paper-based method of document management (Mallela et al., 2020). Project stakeholders may see the advantages and benefits of construction partnerships in digital project delivery as a result of the greater integration of information technology. Before exploring the notion of e-Ticketing, this section discusses the context and breadth of this study's emphasis on digitization in highway development. The part that follows examines briefly the concept of digitization in the construction industry, as well as highway construction challenges that are related to and will influence the acceptance and implementation of e-Ticketing technology. Electronic plans, as-builts, reviews, approvals, contracts, communication, quality assurance, and material ticketing are some of the major components that the Federal Highway Administration (FHWA) believes should be included in the e-Construction framework (FHWA 2018). The Federal Highway Administration (FHWA) is a staunch supporter of the implementation of electronic construction in the transportation sector. In point of fact, e-Construction is a crucial component of the Every Day Counts effort that is being carried out by the FHWA. It incentivizes quicker completion of projects, higher levels of safety, and lower levels of damage on the environment (FHWA 2021). While the departments of transportation in a few other states are conducting pilot tests of newly created technologies at the same time, many other states have already put certain components of e-Construction into practice. (FHWA 2020). Implementation of e-Construction in state DOTs has numerous benefits, including, but not limited to, faster payment transactions at every level, faster project delivery, increased organizational efficiency, and eliminating physical documentation and manual data entry. However, executing an e-Construction system presents a number of obstacles, the most significant constraint being the cost of installation (Mohamed and Tran 2022). The majority of contemporary e-Construction systems are available as commercial-off-the-shelf software (COTS). These systems are often invoiced annually at a pre-license charge. The training of personnel and the buy-in of contractors and/or subcontractors are further difficulties. Road infrastructure digitalization may be classified into two types, according to Cruz and Sarmento, asset-related and service-related. Rather than studying computer technology as a means of providing services, the primary focus of this research is on providing infrastructure support services. Design and construction teams are increasingly turning to the digitization of assets as a primary means of streamlining their processes. Automation and information and communications technology (ICT) are the two main types of computing technology in the construction industry (Perkinson et al., 2010). Worksite operations like as surveying, equipment control, and prefabricated module installation all employ GPS and sophisticated robotic systems to be replaced or improved by construction automation. Constructive IT is a term for the use of computer systems that are capable of recording and arranging information in order to analyze it. e-Ticketing technology, which includes both automation and communications technology, is the focus of this investigation.

3.3.2. Problems in Highway Construction

Problems in highway construction range from labour shortages to document management to cost overruns to injuries/fatalities to delays in the schedule (Creedy et al., 2010; Kermanshachi et al., 2017, Habibi et al., 2018; Wang et al., 2017). As stated by National Cooperative Highway Research Program (NCHRP), "DOTs are managing bigger highway networks with fewer in-house people than they were 10 years ago". For the 40 state transportation departments studied by Taylor and Maloney from 2000 to 2010, the total number of full-time equivalent employees decreased by 9.68 per cent, indicating a significant labour shortfall in the state transportation departments studied. Most construction projects have cost and schedule overruns (Vidalis and Najafi 2002), which can be caused by the cost of utilities, weather-related damage, delays in material delivery, quality problems, and material reconciliation, resulting in construction costs exceeding budgets and projects being delayed. Vidalis and Najafi 2002 When working on a project, it is common for a contractor to be required to meet a range of criteria in order to deliver project information and records, such as invoices for supplies and other paperwork. Documents that need to be migrated to a system, necessitating re-entry of information, or remain in a cumbersome and difficult-to-access paper format are common in the construction industry since most of the work is done on the ground.

3.3.3. Overview of e-Ticketing

An essential component of electronic construction is e-Ticketing. Electronic ticketing (e-Ticketing) has been piloted by many state DOTs including Iowa, Florida, North Dakota, Utah, and Virginia (Nipa et al. 2019). As a pioneer in e-Construction practices and technologies, Iowa DOT was one of the first state departments of transportation to develop and deploy an e-Ticketing scheme. All paving projects in the state have been effectively implemented using e-Ticketing (Ohio DOT and Iowa DOT 2016). Additionally, e-Ticketing isn't limited to HMA's activities, e-Ticketing may also be used to digitalize aggregate and concrete, steel and precast materials, and asphalt emulsions (FHWA 2020). In general, e-Ticketing systems use a combination of software and hardware, however, specifics vary from vendor to vendor. In order to secure an asphalt factory or a paving project worksite, geofences are employed. This method of tracking asphalt is done by using GPS sensors that are installed on trucks. Asphalt plants may produce an electronic ticket that contains all the relevant delivery information such as truck number and material type using an e-Ticketing software package installed on the computer. When a vehicle hauling material arrives at a construction site and enters a pre-defined region, a geofence will cause an alert to be sent to state DOT inspectors working on the project. When the software application is installed into a mobile device, the inspector has the ability to record the material yield, enter the material temperatures that were recorded at the work site, and confirm receipt of the electronic ticket. It is possible for stakeholders to see real-time information and quickly compile reports from the electronic tickets they get from the event. There are several advantages to using an e-Ticketing system. Electronic data collection on load delivery allows for safer and more efficient inspection (Sturgill et al. 2019), faster project delivery and payment (Schultz 2020), and reduced effort for ticket management, as well as near real-time comparisons of theoretical tonnages and temperatures to real-time tonnages and temperatures (Subramanya and Kermanshachi 2022). Additionally, inspectors' exposure to potentially dangerous situations in the workplace would be reduced, and contractors' operating efficiency may be improved (Dadi et al. 2020). When it comes to pavement performance, knowing exactly what loads were applied at a certain spot would be useful information for state DOTs to have access to through an e-Ticketing system (Embacher 2020).

3.4. Research Methodology

Research methodology is a system of approaches employed in a certain area of study (Oxford Dictionary). The methodology might also have a basic definition, such as the strategic procedure of performing a study. The major technique of data gathering in this study was semi-structured interviews with highway construction managers and information technology professionals from construction organizations. Semi-structured interviews allow the researcher to delve deeply into a topic while also allowing for a conversation style in which clarifying questions may be posed. This study included thirteen interviews with people who had been exposed to e-Ticketing technology in some form. According to proven research, thirteen interviews are an appropriate target for qualitative data collection (Guest et al., 2006). The interviewees were all asked questions from the semi-structured guide, and each interview lasted 45 to 60 minutes. Participants in the research were chosen based on their understanding of the issue of using mobile devices on construction sites or their involvement in assisting others with technology implementation. The complete framework adopted in the study is represented in Figure 3.1.

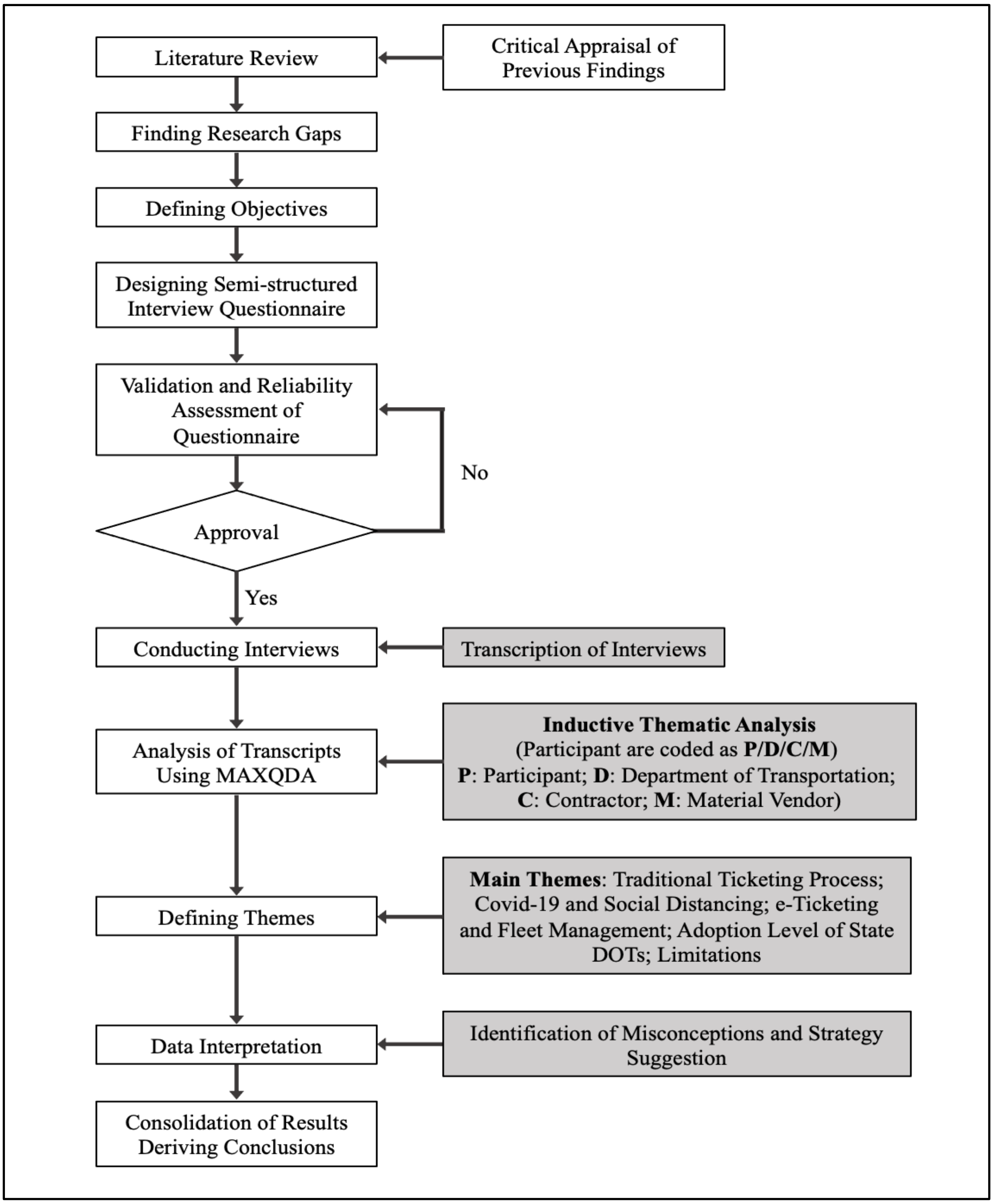

Figure 0-1. Research methodology adopted

The methodology section is further broadly broken down into 2 groups which are data collection and data analysis which are explained in detail below. The study developed research objectives prior to the data collection process through the process of analyzing previous literature and by findings significant gaps in the literature. The semi-structured interview guide was created with the following research objectives in mind as the major emphasis.

1. Identify inefficiencies in the traditional ticketing process and problems experienced in the delivery of materials, inspection/testing records and ticket documentation in day-to-day highway construction operations.
2. Identify limitations and reasons for the delay in the implementation process of the technology. The focus is on identifying any misconceptions relating to the technology utilization and standards in adoption.
3. Identify various benefits of the e-Ticketing system, document adoption levels of different state DOTs, and standards on the mandating the platform.
4. Identify key strategies which will help practitioners to implement and scale the technology throughout the state.

3.4.1. Data Collection

The nature of an interview should be compatible with the research questions and goals, the study purpose, and the research approach used. Interviews can be categorized in a variety of ways including structured, semi-structured, and unstructured. In this study, semi-structured interviews were performed, with the goal of providing each interviewee with the same context of questions. Semi-structured interview questions are often phrased in a generic manner at the outset and are likely to change as the interview goes when follow-up questions are added based on the participants' responses. The research team conducted 13 semi-structured interview sessions and the participants were from all the stakeholders relating to the e-Ticketing technology (State DOTs, material vendors, general contractors, and consultants). The selection of various types of participants which comprised of different stakeholders guided the research study with an in-depth understanding of various aspects of technology implementation and problems related to highway construction. The participants were chosen and inducted into the research study with support from the National e-Ticketing Taskforce which is an organization aimed at mandating the use of e-Ticketing platforms throughout the United States. We aimed to stratify the sample by selecting participants from a diverse set of states which have different adoption levels of e-Ticketing and selected participants who are from material vendors and general contractors' sides as well. The demographics of participants and their association are shown in Table 3.1. Most of the participants chosen had more than 10 years of experience in the highway construction industry and the participants with less than 5 years' experience were chosen to understand the change in the perception of technology by a new generation. The potential participants were invited to participate in the research study through their organization's email addresses. The interview sessions were conducted virtually through Microsoft Teams. The research team scheduled the group discussion dates and times prior to the meeting and sent the participants URL links. The interview sessions lasted approximately 45 minutes to 1 hour. Two facilitators moderated the interview sessions by using a semi-structured guide of questions. These questions were designed to allow participants to discuss their experiences and ideas generously. At the beginning of the interview sessions, the facilitators provided participants with general information about the study and sent them a link to a consent form previously approved by the UTA Institutional Review Board (IRB) to obtain their online consent. Those who were unable to use the link to give their consent gave consent verbally.

Table 0-1. Participant Information

	Organization	Position	Experience
P1	Florida DOT	State construction pavement engineer	26
P2	Washington DOT	Assistant state construction engineer	16
P3	Kansas DOT	Director of project delivery	21
P4	Massachusetts DOT	State construction engineer.	15
P5	Indiana DOT	Highway engineer	7

P6	Indiana DOT	State construction engineer	12
P7	Delaware DOT	Chief of construction and materials.	25
P8	California DOT	Senior construction engineer	20
P9	Aggregate Industries (Supplier/contractor)	Contracting logistics manager	8
P10	Oregon DOT	Senior quality assurance engineer	15
P11	EIV Technical Services (Consultants)	Construction Inspector	2
P12	Haulhub Technologies	Vice President of Industry Relations	22
P13	Haulhub Technologies	Customer sales manager	15

3.4.2. Data Analysis

The planning of a research study requires a thorough grasp of various methodologies. Following the identification of the philosophical perspective and research paradigm, it is necessary to determine how to approach the research study from a reasoning standpoint. The inductive approach describes a situation in which research begins with data collection to investigate phenomena in order to produce or construct a theory or explanation (Saunders et al., 2016). The inductive technique entails developing theory from actual fact, progressing from individual observation to the declaration of a general pattern, as opposed to the deductive approach, which requires moving from general to specific. Its goal, unlike the deductive technique, is to construct theories rather than test them. In this study, the authors employed the inductive technique, which begins with the authors acquiring comprehensive information from participants and then organizing it into categories or topics. These ideas were turned into theories or generalizations, which were then compared to current research on the subject (Creswell, 2013), Figure 3.2 depicts the inductive logic of research. The interview sessions were audio-recorded and transcribed by the researchers. The replies of each participant were coded as P1(D/C/M) (P: Participant; D: Department of Transportation; C: Contractor; M: Material Vendor). To begin, all interview data based on participants' replies to each question were verbatim transcribed. The transcripts were examined for the correctness and to develop coding categories and subcategories in accordance with the study's objectives. The study's data were analyzed with MAXQDA 2022, qualitative data analysis software, using the inductive thematic analysis approach. Thematic analysis is a technique for discovering, evaluating, and reporting patterns in data (Braun and Clarke 2006). This study is concerned with the coding, examination, and patterns found in the recorded data. The information's themes are important and related to the specific study issue. In this study, an inductive thematic analysis will be used, which means that the themes found are strongly related to the data itself (Patton 2014). This technique was selected because deductive analysis would involve a pre-existing or framed topic, so eliminating some of the unknown themes obtained straight from data. If the data was obtained particularly for the research, the themes may have little resemblance to the exact questions that were asked of the participants in this technique. A three-step data analysis technique was applied during the analysis stage. The first phase entailed identifying codes "meaning units" from the interview form responses of the participants. The codes were organized by grouping related ones into a category or topic and isolating different ones into separate groups. The meaning unit codes were sorted and placed in their emerging categories in the second stage, and the categories were evaluated for themes or patterns (See Appendix B). During the final stage of analysis, the categories were analyzed for in-depth meaning and interpretation.

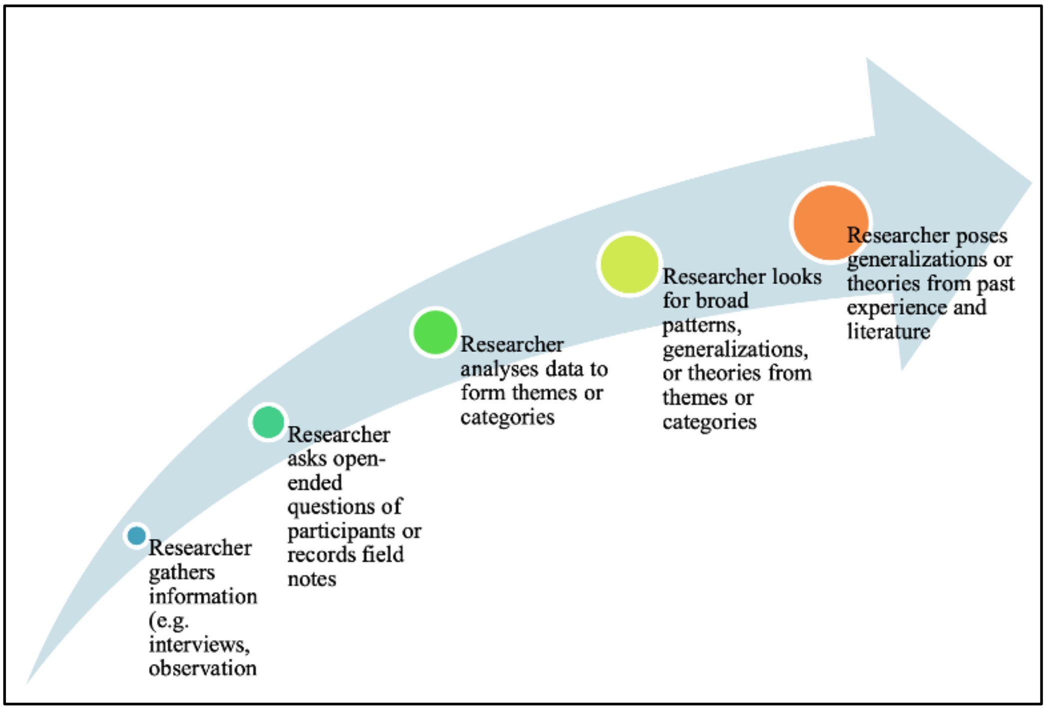

Figure 0-2. Inductive logic of research study adopted by Creswell, 2013

3.5. Results

This section will consolidate all the findings noted by the researchers. The following subsections describe the detailed results regarding the participants' main concerns and issues regarding the use of the e-Ticketing platform. The analysis section has been guided by the MAXQDA 2022 and a code list was rendered, with the codes falling into five categories: (1) Traditional ticketing process (2) Covid-19 and Social Distancing (3) e-Ticketing and Fleet management (4) Adoption level of state DOTs (5) Limitations. The following sub-sections will broadly explain the interpretations and direct quotes by the participants.

3.5.1. Traditional Ticketing Process (Paper tickets)

The study has focused on understanding the traditional ticketing process and its areas of limitations. Paper tickets are expensive, laborious, and time-consuming to produce, sort, record, and archive for both state transportation departments and the private sector (Sadasivam and Sturgill 2021). The semi-structured interview guide contained questions relating to daily operations and the transfer of paper tickets. After careful analysis of interview transcripts by rigorous coding, grouping, and re-grouping of themes/sub-themes, the study has created a flowchart (Figure 3.3) to understand the life cycle of a paper ticket. The flowchart depicts the complete flow of paper tickets from material plant to the state DOT owned warehouse. There are certain inefficiencies in the traditional form of ticketing which can be easily understood with the help of the flowchart. The flowchart was developed solely by the transcribed data. The codes have been regrouped to indicate common themes and the repeated themes and sub-themes have been deleted to only include novel content. The various directional sub-themes are (1) Manual work (2) Scanning and storing tickets (3) Paper tickets (4) Safety (5) Documentation staff. It is very important to understand the process of traditional ticketing to notice the benefits in the implementation of e-Ticketing software. It was also visible that, state DOTs do not have a common procedure the management and documentation of paper tickets.

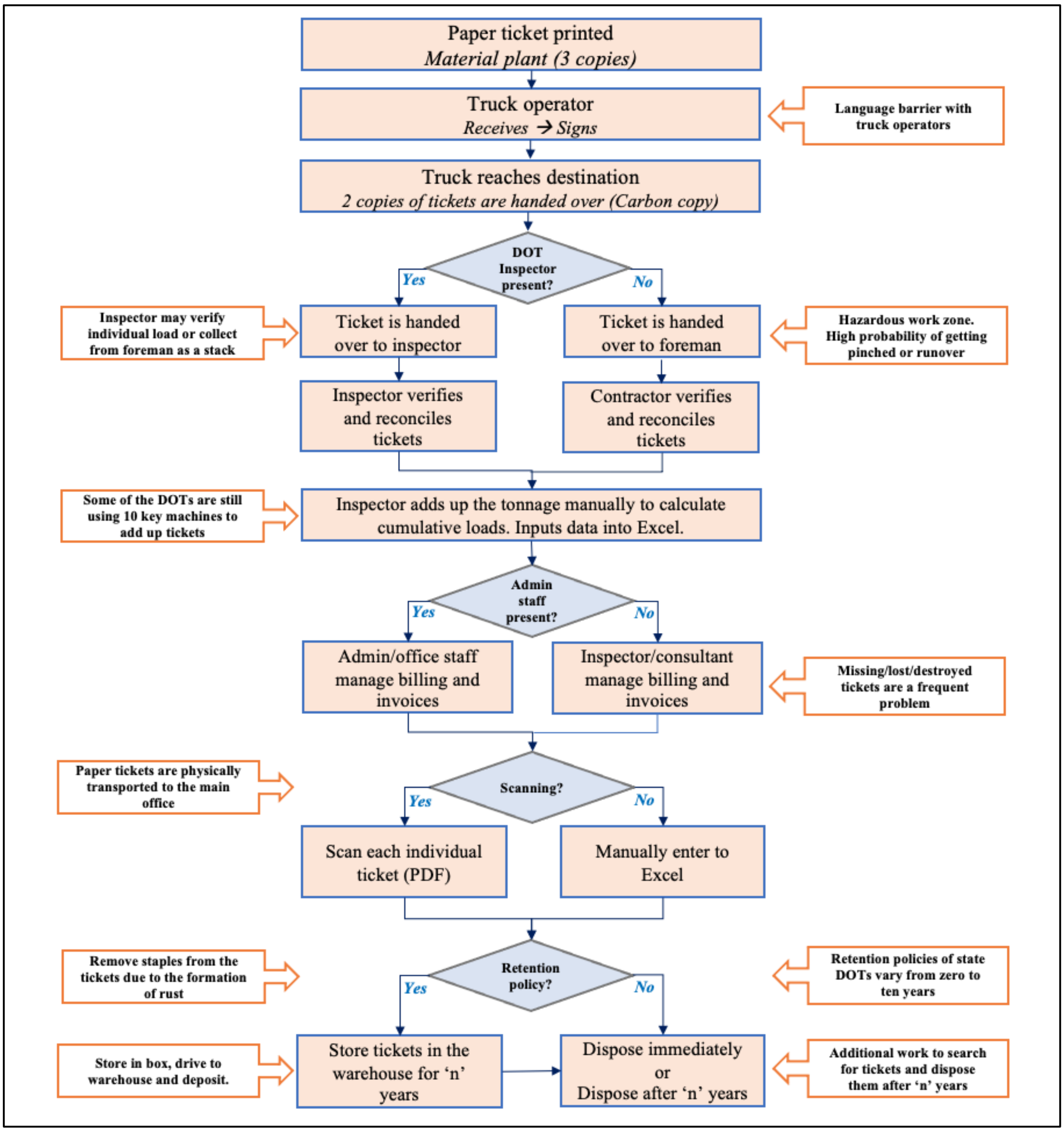

Figure 0-3. Life cycle of a paper ticket

3.5.1.1. Manual Work

The traditional process of paper ticketing has a lot of inefficiencies which was clearly observed in the transcripts. Firstly, at the material plant, when the ticket is printed, the plant operator will print 3 copies of the ticket. The operator will rip his copy of the ticket and send two copies of the ticket which the dump truck operator will receive. The dump truck operator (who is mostly a third-party trucking agency) will receive the ticket and usually signs them. This iterative process is time-consuming, and the participants expressed a language barrier between the plant operator and the third-party trucking agency's operator. There are frequent instances where the dump truck operator does not send the tube back which might lead to delays. Secondly, when the dump truck reaches its destination, a contractor's engineer notes down the truck number, the time it got there, and the location of the pour. This data is often used to tally the tickets at the end of the day and make sure everything is consistent. Before the pour, the inspector present at the site verifies and either accepts or rejects the load. If the inspector is not present at the site, a contractor representative (usually a foreman) collects the ticket and attaches them to a clipboard, which the inspector will later collect the stack of tickets and verify them with the pour. With all the paper tickets in hand, the inspector then must add up all the quantities in the paper ticket to calculate cumulative loads. Some of the state DOT inspectors are still using the 10 key systems (Figure 3.4) on-site to calculate the cumulative tonnage and check the project progress.

Figure 0-4. 10 key machines used by inspectors

Lastly, at the end of the shift, the inspector deposits all the paper tickets at the area district office. The administrative staff will then sort through all the paper tickets and scans them one by one into the document management software. Later, the staples from the ticket are taken out due to the possibility of the formation of rust which will erode the quality of paper tickets over time. The administrative staff will then have to grab the box of tickets and drive to a warehouse which is usually away from the district office to deposit all the tickets. Depending upon the retention policy, the administrative staff have to dispose of the tickets stacked in the warehouse after ‘n’ years which is another additional manual work. The sub-themes derived and quotes from the participants are depicted in Table 3.2.

Table 0-2. Sub-themes and quotes related to manual work

Sub-themes		Quotes
Inspector responsibilities	P1:	*“End of each day at the end of the project, they've got to reconcile those tickets.”*
	P3:	*“Verify that the material that they're supposed to be delivered is what they're delivering. Then we have a person on-site who's receiving and they're documenting every time a new truck gets on. What truck number? What time do they get there? where they're placing the material on the job?”*
	P6:	*“When you get the tickets at the end of the day, you can start to pair them up and say so I've got this log of loads that have arrived on the job site and ticket number one went with this load and ticket two with this load and sometimes you get to a ticket, and you say wait a minute this ticket never showed up on site.”*
	P7:	*“The field staff when they're closing out the books would have to get everything in a file and then take it to our main administration building.”*
	P10:	*“Some of them are old school and use the 10 key machine. Verify the quantities. That is essentially just the quantity calculation it to verify quantities for payment and just satisfying the requirement for two tallies, and again whether it's an Excel or whether it's on even an old school 10 key.”*
Admin staff responsibilities	P7:	*“Admin would have to go in and remove all the staples and all the paper clips because you can't have any metal in there because it will rust.”*
	P8:	*“There is also one more issue, disposing them after 3 years and locating them in the store house.”*
	P10:	*“Area District office and then from there the tickets get scanned and get documented into the express software.”*
Plant operator responsibilities	P3:	*“When a paper ticket is printed, it takes time. The plant operator needs to grab the ticket off the printer.”*
	P9:	*“He then will rip his copy off a lot of times he stuffs it in a tube and then sends the tube to the truck and the driver needs to park his truck, get out of the truck. Over the ticket booth, grab his or sign the ticket and then send a copy back. Sometimes he's going to track down the crew once he's on the job to give him the ticket. Line of trucks lined up in front of you and somebody drives off with the tube*

	or they don't send it back or there's a language barrier it, it makes your life miserable at times."

3.5.1.2. Scanning and Storage of Tickets

The policies, standards, and regulations on how to maintain and document a paper ticket vary drastically from state to state. Most of the states are still scanning each individual paper ticket and retaining the physical copy of tickets for 'n' years in the DOT owned warehouses. Some of the states are manually entering ticket data into Excel files and are not required to scan each ticket. Few other states are scanning all the paper tickets into PDF format and disposing of the hard copy of tickets immediately with no retention policy. The various types of retention policies and standards for storing the tickets were grouped into a common theme to analyze the data. The sub-themes derived and quotes from the participants are depicted in Table 3.3.

Table 0-3. Interview sub-themes and quotes relating to scanning and storage of paper tickets

Sub-themes	Quotes
Document management	P1: *"At the end of each day at the end of the project, they've got to reconcile those tickets and. We've always required them to scan the tickets."* P2: *"Our construction manual stated that you had to sign each ticket. So, we have some people, for example, getting digital photos of tickets, printing them out, signing the ticket and then scanning them back in."* P7: *"Sometimes you'll put it in an Excel sheet, but you still must maintain that paper ticket is back up."*
Retention policy	P4: *"It was all paper tickets that were recorded. No scanning, stored in hard copies. The retention policy is 7 years."* P7: *"It was all paper and stacked in a blue box, and it goes in the archived building. It sits there for 10 years."* P8: *"Right now, we're not uploading anything to a database. We're storing paper tickets and boxes and discarding them after the three years."*

3.5.1.3. Paper Ticketing Inefficiencies

Each state will produce approximately 3 – 6 million tons of asphalt each year for highway and infrastructure projects. On top of that, there are concrete and aggregate ticket loads as well. For medium-sized states such as Indiana, Washington, and Florida, the total number of paper tickets issued and recorded by the state DOT will range from 250,000 to 350,000 tickets each year. All the information in the paper format is dead information but has the potential to provide valuable insights into daily operations. The paper tickets are never retrieved unless a project is being audited for discrepancies. Some of the material plants still use the old DOT matrix printers with carbon copies, and some of the data in the tickets are difficult to read. There are instances where the inspectors have lost paper tickets (lost in the car, destroyed by asphalt, torn tickets, illegible data) which are leading to delays in payments and billing. In many projects, the truck operator hands over multiple copies of the ticket to the foreman (contractors and DOT) which is again a cumbersome process. The codes and themes used to understand the inefficiencies of paper tickets are depicted in Table 3.4.

Table 0-4. Interview sub-themes and quotes relating to paper ticketing inefficiencies

Sub-themes	Quotes	
Legacy systems	*P1:*	*"Old dot matrix printer with carbon copy. Is it an 8? Is it a three? Is it a 6 and 9? And you can hardly tell what the numbers are and so it could be a little bit challenging there."*
	P5:	*"Sometimes the paver operator would get they come with two tickets, one for our side and one for the contractor side."*
	P4:	*"It's sort of dead information. It's kind of useless unless someone's going to actually audit a project."*
Human negligence	*P10:*	*"You don't know that it's a daily basis, but it's not an uncommon thing that happens is a missing ticket."*
	P11:	*"I've seen situations where there was lost ticket and the customer would refuse to pay for those loads because they didn't have a paper receipt. I've seen tickets get destroyed with asphalt."*

3.5.1.4. Safety and Hazards

All the participants expressed concerns and acknowledged that the collection of paper tickets near the dump truck is a highly hazardous zone. Getting run over or pinched by a dump truck is one of the highest possible mishappenings during the operation. The construction of highway infrastructure usually happens during the nighttime in city-limit areas where there is traffic during the day. The night construction activities pose more risk to the inspectors and engineers working around the dump truck to inspect and collect the paper ticket loads. During the daytime construction, the inspectors will have to work in proximity to traffic and the only thing that separates them from the high-speed traffic will be a couple of cones. The sub-themes derived and quotes from the participants are depicted in Table 3.5.

Table 0-5. Interview sub-themes and quotes relating to safety

Sub-themes		Quotes
Hazard zone	P1:	*"You might have a cone and then you got traffic going by on an interstate and they might be going 60 to 70 miles an hour."*
	P3:	*"Getting run over by a triaxle or a truck on the job or pinched.*
Operations	P3:	*"That's one of the most hazardous places you can be around the dump truck, right? So particularly when they're backing up all the time."*
	P8:	*"A lot of our work is done at night and in crowded areas, any inspector not paying attention – it could be deadly. You have to go close enough to the truck to grab a paper ticket."*

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. Figure 3.5 compares the view from the driver's seat of a truck with a ground view of an inspector who is of average height and reveals that the driver in the truck has zero visibility of the inspector.

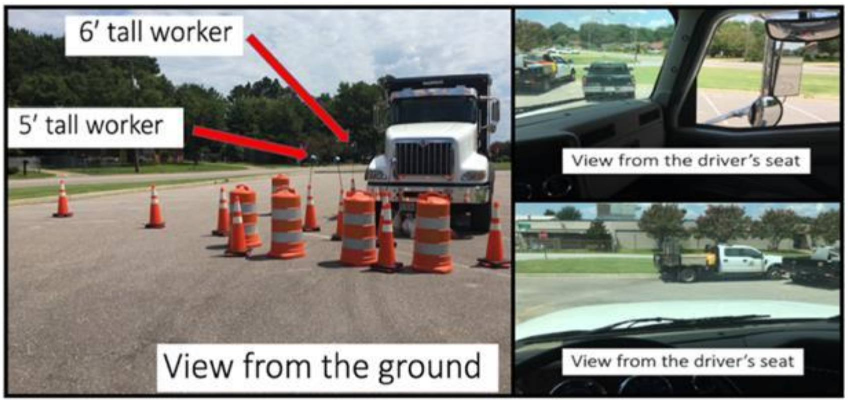

Figure 0-5. Driver's view of inspectors/workers

3.5.1.5. Documentation staff

The administrative staff in DOTs vary drastically from state to state. The responsibilities of the documentation process significantly differ with some states not having a common procedure to document the paper tickets. The roles of the administrative staff are sometimes overlapped with the duties of inspectors or consultants. In a few states, it is the responsibility of the consultants or inspector to scan each individual load ticket into the document management software. The administrative staff responsibilities also include documenting change orders, billing invoices, scanning paper tickets, and storing all paper tickets in a warehouse depending on the retention policy. The different types of handling of work and responsibility of the documentation process are depicted in Table 3.6.

Table 0-6. Interview sub-themes and quotes relating to documentation staff

Sub-theme		Quotes
Type of staff	P1:	*"Project administrators over that project. They'll have inspectors and then on that on a project, they'll have a contract support specialist."*
	P5:	*"Administrative staff go through and make sure you move all the paper clips and scan each ticket."*
Number of staff	P2:	*"Each project office typically has probably two to six people who handle materials well, any kind of documentation for materials to change, orders to payments."*
	P6:	*"We have six district offices, and each one of those six district offices has two people."*
	P3:	*"We have 25 – 30 inspectors throughout the state who are managing the documentation"*
	P7	*"As Delaware is a small state, we have 4 administrative staff for the entire state whose sole responsibility is documentation"*

3.5.2. COVID-19 and Social Distancing

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 (Pamidimukkala et al., 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 believed to operate safely amid lockdowns and the pandemic. A few DOTs, including those in the process of developing specifications for e-Ticketing, have also adopted contactless delivery standards to maintain social distancing. Most state DOTs have partially implemented e-Ticketing which incorporates sending PDF/JPEG versions of the tickets directly to engineers and inspectors to avoid human-to-human interaction. Some of the participants reported that there was an increase in construction activity as the roads were empty with no traffic. States like Delaware reported that their state allowed construction projects to move ahead with full fledge. This created an awareness and a need for implementation standards for the adoption of e-Ticketing systems across several states. There were instances where the collected paper tickets at the site were collected in a plastic bag and then disinfected under sunlight for 48 hours and then compared alongside the quantities. Some states mandated vaccination for their employees which resulted in states letting go a lot of their prime experienced inspectors and engineers. The sub-themes derived and quotes from the participants are depicted in Table 3.7.

Table 0-7. Interview sub-themes and quotes relating to Covid-19

Sub-themes		Quotes
Photo/Email of tickets	P1:	*"We wanted to do something for social distancing. And so, at the time we wrote a memo that said you had to do some form of contactless ticketing, it could be taking photos of tickets it could be emailing the information and we had about four different options."*
	P3:	*"COVID really got us going on this right. The whole idea about not transferring materials between people with tickets, with handing tickets off. We just said just send us the copy of the ticket. You know, one way or the other."*
Paper tickets	P8:	*"Send it with the last truck out and we'll just get one stack of tickets rather than going up to every truck and then we'll go ahead"*
	P13:	*"Between Caltrans and granite construction where they were actually like taking the tickets, putting the tickets in a plastic bag and then leaving them out in the sunlight to like to disinfect for like 2 days"*
Vaccination	P2:	*"Through COVID in our state, they were requiring vaccinations, so they just well let go of a number of people whom you know didn't get vaccinated which resulted in shortage of workforce."*

3.5.3. Fleet Management and e-Ticketing

The two standalone technologies have overlapping features and have been pilot tested by various DOTs. The fleet management application deals with the truck efficiencies and live tracking of dump truck as soon as it leaves the plant with the help of geozones and geofences. All the pilot tests conducted from the year 2013 to 2018 included features of fleet management in them such as GPS responders, setting up geofences and geolocations. As all the pilot tests were conducted by the state DOTs, they failed to recognize the return on investment from the platform as the initial investment skyrocketed with the use of GPS transponders. This resulted in state DOTs rejecting the software as they had to purchase the technology for the entire state which was not in the good interest from the perspectives of state DOTs. The sub-themes derived and quotes from the participants are depicted in Table 3.8.

Table 0-8. Interview sub-themes and quotes relating to e-Ticketing and fleet management

Sub-themes		Quotes
Stakeholder perspective	*P4:*	*"We have not ventured into tracking trucks. I think it'd be more useful for the contractors and timing their trucks"*
	P2:	*"So, in short, it doesn't directly affect the state dot and it is to do with the general contractors."*
	P8:	*"My perspective right now as evaluating the technology. I would say that that's not something that we would necessarily be interested in is tracking the live load because I think that opens us up to some liability for the state DOT"*
Investment	*P7:*	*"When you start putting GPS on to the trucks, the investment cost will skyrocket."*
	P5:	*"Not doing the GPS, not doing the geofence, your cost increases exponentially and it's cost prohibitive. It's impossible, because if you had to put at GPS locator and every single dump truck in the state"*
Pilot test	*P6:*	*"We don't have GPS tracking on the truck. We found that to be a barrier in some of our pilot testing. So when we move forward with the ticketing, we remove the GPS requirement for truck tracking."*
	P7:	*"We made an attempt to run a pilot back then they liked to run and putting GPS on trucks. To pull it off like the functionality of that, like the logistics of putting GPS and every single dump truck that's going to make the job very difficult. So, we ended up abandoning the whole GPS and trucks initiative, going at different route for E ticketing."*

3.5.4. Adoption levels of DOTs

In this section, we will discuss the extent to which the level of adoption has changed, the implementation strategies that the DOTs will use, and the impact that Covid-19 will have on the e-Ticketing platform. Several departments of transportation have conducted pilot projects using the technology for asphalt and concrete paving. In order to gather information about the levels of adoption rate, a large number of memorandums, letters, specifications, and DOT websites were reviewed. Currently, TRB claims that since the beginning of the epidemic, a total of 14 states have undertaken pilot projects and research, 5 are in the midst of implementation, and 15 more have begun working towards e-Ticketing. Figure 3.6 illustrates the number of states that had already implemented e-Ticketing in its entirety prior to the epidemic, as well as the percentage of states that had only partly implemented it in response to the growing urgency of the pandemic and the need for social distancing. Because of the coronavirus, more than 32 percent of departments of transportation (DOTs) have implemented specifications, including e-Ticketing platforms, in order to keep their employees safe by maximizing the benefits of social distancing. These specifications were deployed to general contractors and software vendors. 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. Departments and agencies have begun initiating pilot tests. Additionally, a new task force was launched by the federal government. Memorandums, specifications, reports, and requirements have been issued by a variety of agencies; the degrees of acceptance by a variety of state DOTs are given in Table 3.9.

Table 0-9. Adoption levels by various state DOTs

State	Adoption	Mandate statewide
Florida DOT	Partial implementation	Contractor driven
Washington DOT	Partial adoption	Contractor driven

		Mandated electronic copies of tickets (PDF)
Kansas DOT	Full scale adoption	Present – contractors driven Mandate – June 2022
Massachusetts DOT	Full scale adoption	Past – Contractors driven Present – Mandated statewide
Indiana DOT	Full scale adoption without mandate	Contractor driven
Delaware DOT	Full scale adoption for HMA	Mandated from March 1st 2022
California DOT	Pilot test	Pilot testing phase with 2 vendors
Oregon DOT	Pilot test	No mandate

3.5.5. Overview of Benefits

The e-Ticketing system may be particularly useful in ensuring that time-sensitive and perishable goods, such as asphalt and concrete, are delivered to the appropriate site at the precise moment they are expected to be there. Adopting integrated technological tools as soon as they become available is essential to realizing the full potential of a truck in terms of monitoring and maintaining the material's quality while it is in transit. This is the key that will unlock the truck's potential. The way people live has been fundamentally altered as a direct consequence of developments in technology, which have also made it possible to do tasks in more efficient and expedient ways. The present research investigates the effects of implementing electronic ticketing in terms of four distinct categories: Project overview, productivity, transparency, and cost savings which are jotted alongside their sub-themes and quotes in Table 3.10. The traditional paper-ticketing method of processing materials for transportation projects is inefficient and increases project costs and duration (Sturgill et al., 2019). In the midst of the coronavirus outbreak, transitioning to digitization platforms such as e-Ticketing has enhanced the process and has been welcomed even more swiftly (Oberg 2021).

In every building project, raw materials and equipment account for almost half of the total cost. The pace at which raw materials and equipment fleet are used is linked to the project's growth. The effect of introducing e-Ticketing on the cost savings ranges from cutting down the workforce and hiring fewer consultants to do the same job. The resident engineers or the area engineer who will be responsible for inspectors or consultants under them can supervise projects effectively with ease and accuracy. Multiple projects can be monitored simultaneously by the area and resident engineers who will have access to project overviews. They can play a major role in reassigning the workforce to areas which require significant inspection duties. The summary reports generated by the software will help resident engineers to know the project progress and completion rate with a click of a button.

The participants mentioned that around 30 minutes to 90 minutes per day of each inspector will be saved by the implementation of e-Ticketing platform. The respondents also clearly stated that the amount of time-savings is directly proportional to the number of tickets produced on the jobsite. The increase in productivity of inspectors and engineers are directly related to the amount of time saved per day per project using e-Ticketing technology. The office/backend workers can also assist in inspection duties as most of their work will be automated and simplified which will in turn solve the problem of workforce shortage within the industry. The technology will also increase cross functional collaboration between all stakeholders thereby increasing transparency. This technology will facilitate the transfer of information through all the stakeholders so that there won't be any discrepancies and reduction in disputes. The technology will render significant cost savings to the DOTs as they can cut down their hiring on consultant staff. The state DOTs will never have to pay for rejected loads and partially rejected loads which is a very usual occurrence in the highway paving industry.

Table 0-10. Interview sub-themes and quotes relating to benefits

Sub-themes	Quotes

Project Overview	P6:	*"Multiple projects can be monitored by the resident or area or construction engineer and have information on the project timeline. The resident engineer who is responsible for many inspectors can have an overview of entire operations."*
	P13:	*"Inspectors and resident engineers will receive daily summary report which includes the complete summary for the day's activities."*
Productivity	P1:	*"The inspectors will have information related to the width, length, and thickness of paving operations. The inspectors can verify the tonnage with the volume."*
	P3:	*"Verifying each ticket load will be efficient. Inspectors need not collect a stack of tickets from the foreman."*
	P8:	*"Concrete loads will have a lot more specifications than asphalt. Inspectors can cross-check with specs as soon as the truck is dispatched and notify the plant owner if there is a mistake in the load"*
	P7:	*"Each inspector will save around 30 minutes per day per project using the e-Ticketing application."*
	P5:	*"A total of one hour per day per inspector can be saved which includes taking easier notes, automated ticket transfer, avoid scanning and live cumulative loads."*
	P8:	*"The time savings are directly related to the size of the job and number of tickets generated on that job. The savings will typically range from 20 minutes to an hour depending upon the project."*
Transparency	P10:	*"Inspectors can have access to the truck's dispatch time and have an approximate ETA of the trucks. They can have real-time information on how many trucks have been dispatched, how many have arrived and how many are in line."*
	P12:	*"e-Ticketing provides a way for information to seamlessly transfer across stakeholders so that everybody in the chain of events, from design to construction, can get instantaneous access to the information with a click of a button."*
	P8:	*"Opening of lanes to traffic and let out press release. Area engineers can inform the traffic authorities beforehand if there is a delay in the process of paving operations."*

Cost savings	P3:	*"Projects with multiple inspectors on-site can cut down the workforce. Especially where they must use consultant inspection, if they can use two consultant inspectors instead of three then that would be a quantifiable saving that would be easy to track."*
	P7:	*"Rejected loads can be kept in the record and made sure the state does not pay for any of it. Partially rejected loads are also well documented in the e-Ticketing software."*
	P3:	*"Usually in concrete pours, there are two inspectors, one to accept the load and one to watch the vibration and consolidation process. This team of two inspectors can be cut down to 1 inspector eventually."*
	P11:	*"More granular with the data and overview at actual truck rounds and the platform will point right out that if they are over trucked or under trucked."*
	P8:	*"Backend administrative staff can be used to address the problem of workforce shortage as majority of their work will be automated."*

3.5.6. Limitations

The limitations faced by the stakeholders in the implementation process of the e-Ticketing technology can be classified into 2 categories which are (1) Major limitation (2) Minor hindrance. The major limitations include "Internet Connectivity" and "High Investment and ROI" which directly affects the implementation process of the e-Ticketing technology and are key reasons for the slowdown in the adoption of the technology which was supposed to be implemented nationwide a decade ago. The minor hindrances include "Change management", "Training of employees", "Data integrity" and "Law enforcement" which are discussed below in detail.

3.5.6.1. Major Limitation 1

Internet Connectivity: At asphalt plants, internet connection is a concern, as well as having these facilities run the latest version of the software is another concern. The very first investment a plant owner must make is to replace their legacy systems. In remote locations, plants that are seldom utilized may not merit the expense of upgrading them. It was also noted that rural areas have bad reception and coverage. Some of the projects which run through different terrains have small spots/areas with no access to the internet and small material plants which are in rural areas will have no internet access and some are still issuing handwritten tickets

⇒ (P1) "Certain parts of Florida are rural. You might not have good connectivity. So, reception is bad."

⇒ (P7) "You'll have pretty good connection at a lot of locations, but you do occasionally run into some issues. Or you might just have weird spot where you think you'd have a good connection. There would be some little spot on the project. It just doesn't have connection for some reason."

⇒ (P2) "But then have some areas that do not have good self-coverage in Washington state with some of our mountain passes and more rural areas."

3.5.6.2. Major Limitation 2

High Investment and ROI: Most of the pilot projects from 2013 have used GPS transponders in the trucks and have set up geofences and geolocations to monitor the live location of the truck. This GPS live tracking feature of material trucks has no benefits from the DOT perspective as observed in Table 3.8. The inclusion of GPS transponders in every truck drastically increases the investment cost of the technology. Also, the GPS transponders will have its own liability issues which the state DOTs do not want to encounter. The direct quotes from various state DOT participants who expressed their concern relating to e-Ticketing and GPS transponders are as follows:

⇒ (P7) "We started having this conversation probably seven years ago. We made an attempt to run a pilot back with GPS on dump trucks. When you start putting GPS, your costs skyrocket and to scale up the functionality and logistics of putting GPS on every single dump truck felt impossible. So, we ended up abandoning the whole GPS and trucks initiative and disbanded the implementation"

- ⇒ (P3) "It's not as critical to us that we're tracking that truck movement with GPS at all times, right, as long as we know when that truck got dispatched from the plant and when it showed up at the project site, we're not really concerned about the exact location of dump truck, it's actually a liability for us to know the exact location"
- ⇒ (P8) "Typically, we have not ventured into tracking trucks due to its high investment cost and liability issues. I think it'd be more useful for the contractors and timing their trucks, but for us, if everything continues at the right speed where we're happy with it."
- ⇒ (P6) "We don't have GPS tracking on the truck. We found that to be a barrier in some of our pilot tests. So, when we moved forward with the e-Ticketing, we removed the GPS requirement for truck tracking. So, we're not interested in fleet management, we're more interested in just the ticket side of it."
- ⇒ (P4) "Not doing the GPS, not doing the geofence, your cost skyrocket and it is cost prohibitive. It's impossible, because if you had to put at GPS locator and every single dump truck in the state. It's a nightmare tracking these things."

3.5.6.3. Minor Hindrances

Following are the minor interruptions noted in the study which can be overcome with implementation standards (1) Data integrity - Some of the state DOTs are concerned about who can access their data. Hesitance to grant permission to deposit electronic tickets directly into their document management software. Many state DOTs have in-house IT departments who have shown pushback towards the implementation of the technology. (2) Training of employees - The inspectors and engineers must be trained on multiple software if the state has left it to the contractors to drive the initiative. The inspectors have expressed concerns towards learning various software and its utilization which is often tedious and time consuming. (3) Law enforcement - In most of the states, the truck operator or the hauler needs to have physical copy of a paper ticket of what material they are hauling to show to the law enforcement agencies. This rule has been in place from past several years. When a dump truck is pulled over by the police for any reason, the concerned officers will ask for proof of ticket and the type of material they are hauling. (4) Change management - The hesitation from stakeholders is very high as the construction industry is a slow adopter of any given technology which can be seen through scientific research and analysis. The mindset of stakeholders who have a pushback towards technology implementation do not understand the full potential of the technology. Majority of the stakeholders feel that there is nothing wrong in the traditional format of paper ticketing which is entirely false. Some participants have even reported that the stakeholders are afraid of the technology.

3.6. Discussion and Conclusion

Almost every industry today uses digital technology to expedite operations, reduce paperwork, eliminate manual labor, and reduce total costs. Construction firms are seeing the advantages of adopting construction technologies into their everyday operations and are jumping on board. Highway construction benefits from real-time visibility, efficient material dispatching, enhanced back-office operations, increased fraud detection, less total material waste, and correct invoicing and documentation when technologies like e-Ticketing are employed. This section will discuss the misconceptions in the perception of technology and strategies to over the major limitations addressed in the previous section.

3.6.1. Misconception 1 (Covid-19 and e-Ticketing)

All the state DOTs agreed that coronavirus acted as a catalyst in accelerating the deployment of this technology. It was also clearly observed that the states which adopted e-Ticketing at the time of Covid-19 without any prior pilot projects had a misconception regarding the full abilities of the platform. Some of the state DOTs restricted themselves to obtaining a Photo/PDF version of the paper ticket and failed to understand the full benefits of the platform.

There are instances reported from participants where the digital copies of the tickets were printed out, signed, and scanned back into the document management software. This misconception was created due to the construction manuals stating that all tickets should have a signature.

3.6.2. Misconception 2 (High Investment)

To understand the level of misconception and how this has led to a delay in the implementation process of e-Ticketing, we need to understand the different stakeholders involved in highway construction. The different stakeholders are depicted in Figure 3.6. From the extensive analysis of transcribed data, it was clearly seen that different stakeholders have slightly different requirements relating to the e-Ticketing platform. From the interview transcripts, it was noted that none of the state DOTs are interested in having GPS responders and getting to know the live location of each individual dump truck. Whereas, from the interview transcript of contractors and material vendors, it was observed that they have a keen interest in the GPS responders and knowing the live location of their fleet. The features of fleet management have overlapped with the abilities of the e-Ticketing application, and this has created a decade of a slowdown in the implementation of this technology despite its completely visible benefits relating to safety, increase in productivity and data insights. Table 3.11 provides an overview features and abilities of the e-Ticketing platform and its impact on different stakeholders. The green checked boxes indicate that the feature is essential to the concerned stakeholder and the red checked boxes indicate that the feature is of no use to the concerned stakeholders. As it is evidently seen in the table that the contractor are the only stakeholders who will be reaping the full benefits and utilizing the platform to its fullest abilities. From a careful analysis of all the transcribed data, it was clearly understood that there is a decade delay in the implementation process of e-Ticketing nationwide as the technology has been coupled with fleet management and its features.

Table 0-11. Essential features of e-Ticketing with respect to different stakeholders

Features	State DOT	Contractor	Material Vendor
1. Electronic ticket transfer	✓	✓	✓
2. Manual acceptance of loads	✓	✓	✗
3. Geofence/GPS acceptance of loads	✗	✓	✓
4. Truck loaded time	✓	✓	✓
5. Truck dump time	✓	✓	✓
6. Live cumulative tonnage	✓	✓	✗
7. Live tracking of trucks with GPS	✗	✓	✓
8. Ability to enter temperature along with ticket	✓	✓	✗
9. Ability to take photos of pour/rejected material	✓	✓	✗
10. Fleet performance	✗	✓	✓
11. Operational analytics	✓	✓	✓
12. Digital transfer of tickets without internet	✓	✓	✗

3.6.3. Strategy 1 – Offline Mode

The internet connectivity issue is one of the main limitations which has halted the induction of e-Ticketing platform in the construction of highways and bridges. The transfer of ticket data from the plant to the inspector on-site is one of the most important aspects in the inspection and material delivery process. This can be further supported by inclusion of QR codes or barcodes on the paper ticket or transfer the tickets from operator's device to inspector device through NFC/Bluetooth. At remote locations with no internet access, the plant owners can print the paper ticket with a QR code attached to it which also contains the same ticket data that is encrypted. When the dump truck arrives at the site, the inspector can scan the QR code and jot down the notations/accept or reject/temperature reading on the mobile application. Later when the inspector leaves the site and travels to a location with internet access, the ticket data and the annotations made will synchronize with the exact same load of ticket. This process will help in stopping the transfer of paper ticket from driver-foreman-inspector-admin staff-warehouse and will help all the concerned stakeholders to implement the technology in full scale.

3.6.4. Strategy 2: Dissociate e-Ticketing and Fleet Management

As it is evident from Table 3.8 and the quotes from the participants, the technology must be separated with a thin line of margin so that each stakeholder can reap the full benefits of the platform without having to unnecessarily pay for what they are not using. As of present scenario, there are software vendors who have understood this gap in the implementation process and have slowly drifted away from the inclusion of GPS transponders and setting up geolocations. If the technology can offer only the ticket source documentation for the state DOTs, this will help them to reduce their investment cost by approximately 90%. The available software vendors who have decoupled themselves from the features of fleet management should be rigorously pilot tested by all the state DOTs to achieve a state-wide mandate.

3.7. Conclusion

The industry has long been overdue for digitalization, and the Covid-19 outbreak has served as a catalyst for change. Today, the demand for real-time collaboration necessitates the employment of construction technology as a change driver. Early adopters will face a paucity of knowledge and a scarcity of success stories to encourage them to invest in these technologies in highway construction. The workforce in the construction industry is a key concern, and centralized technology will aid in its resolution. Construction companies will be able to cut labor costs, improve employee happiness, and avoid most hazards by automating administrative operations and improving legal and policy compliance. On highway construction projects, paper-based load delivery tickets are a time-consuming and inefficient technique. Construction inspectors and contractor staff are exposed to safety hazards in work zones when collecting paper tickets from hauling vehicles. Paper-based ticketing is a resource-intensive and sequential process that involves numerous points of contact for handoff. These touchpoints include manually entering information from paper tickets with limited traceability and few subsequent data applications. Tickets that have been misplaced or destroyed are a typical occurrence.

Departments of transportation (DOTs) and the private sector both invest heavily on printing, delivering, sorting, and archiving paper tickets. The paper-based technique necessitates an in-person ticket collector to receive tickets from truck drivers, record tonnage and location, compute yield, and present daily summaries. From the transcripts, it can be deduced that the timesaving can vary from 30 minutes to 120 minutes depending upon the size of the project which is directly proportional to the number of tickets generated. The state DOTs can allocate the personnel who are handling tickets to much significant operations thereby solving the workforce shortage problem while also saving quantifiable costs to the organization. e-Ticketing can alleviate many of the industry's challenges by helping those struggling with declining workforces, cost overruns, and schedule delays. Analysis of the adoption levels of DOTs reveals that from January 2021 to March 2022, many state DOTs have begun pilot testing and mandating the use of e-Ticketing software.

This study suggests 4 key aspects that will assist stakeholders in transitioning from pilot tests to full-scale implementation. Firstly, the DOTs must mandate the use of e-Ticketing systems throughout the state by purchasing the software to reap the complete benefits of the technology. This can only be achieved by decoupling fleet management (GPS transponders, geofences, and geolocation) from e-Ticketing application, thereby taking off 90% of the investment cost of the technology. The state DOTs need to have a single source of documentation which will have APIs built into the material plant and into the state-owned documentation software. Secondly, in areas with no internet connectivity, QR codes must be used as a mode to transfer data from material plant to the on-site inspector mobile application.

This will play a major role in the technology implementation as the paper tickets handover stops at the truck operator and will not complete its life cycle. Thirdly, due to the pandemic's faster deployment of e-Ticketing technology, diverse levels of implementation and regulations have emerged, which vary greatly from state to state. Due to the platform's partial implementation during the peak Covid-19 period, some state DOTs have not fully utilized the platform's capabilities and have merely emailed image/pdf versions of tickets. This has resulted in a widespread misconception of the platform's true capabilities and its ability to simplify and automate day-to-day operations. DOTs that have adopted guidelines only for the purpose of social distancing should also look at the other benefits of e-Ticketing and start pilot programs. Finally, the massive amount of metadata may be utilized to create prediction models for cost reduction and quality assurance. If all construction data is entered into a single database, from contract to material delivery to project completion, it will help in further analysis of the raw data, provide suitable tender pricing, and create a baseline for transportation projects, decreasing cost overruns and schedule delays.

CHAPTER 4

UTILIZING E-TICKETING TO INCREASE PRODUCTIVITY AND MINIMIZE SHORTAGE OF INSPECTORS

Below is a published paper (Chapter 4).

4.1. Abstract

State departments of transportation (DOTs) are constructing and managing more highway projects than ever before despite limited funds and a shortage of inspectors. A few DOTs and general contractors have implemented e-Ticketing technology to increase their workforce productivity and efficiency, but the majority are still using conventional paper methods because they do not fully comprehend the benefits of the technology. The primary objective of this study is to quantify the impact of e-Ticketing technology on the number of inspectors required for a project and on the level of productivity. A comprehensive literature review and stakeholder survey were conducted and revealed that all 20 DOTs reported workforce shortages. A comparison was made between the required number of inspectors prior to and after the implementation of e-Ticketing, and it was found that projects requiring multiple inspectors could reduce their workforce by 25% by implementing e-Ticketing. The findings of this study will enable state DOTs to reduce the number of inspectors on-site, thereby circumventing the shortage of workers.

Keywords: e-Ticketing, Productivity, DOT, Workforce Shortage.

4.2. Introduction

State DOTs have limited inspection personnel and financial resources to meet the increasing demand for highway construction and rehabilitation projects (Oechler et al., 2018; Rouhanizadeh and Kermanshachi 2020; Safapour et al., 2020; Subramanya et al., 2020), and the shortage of inspectors foretells the possibility of quality shortfalls (Taylor and Maloney

2013; Kermanshachi et al., 2017). A recent study conducted by the Indiana DOT expressed the agency's difficulty in staffing over the past decade as a result of inspectors quitting their positions or moving to the private sector. (Cai et al., 2020). The Kentucky Transportation Cabinet (KYTC) also reported a shortage of inspectors, due to the increased demand for construction (Rush 2021). According to Li et al., some state DOTs are unable to replace retiring inspectors and engineers, and Anderson et al. observed that while many state DOTs have improved their ability to retain and manage their workforce, they still face a shortage of skilled employees. The resignation and retirement of highly qualified inspectors and engineers have significant impacts on highway inspection capabilities (Newcomer et al., 2019; Subramanya and Kermanshachi 2021; Nipa et al., 2022).

Researchers are continually searching for new ways to improve the efficiency and operational effectiveness of highway construction by utilizing cutting-edge technology (Nipa and Kermanshachi 2022). A study by the Federal Highway Administration (FHWA) demonstrated that integrating 3D modelling with GPS sensors could yield faster highway construction with greater worker safety. Some organizations have achieved a 50% increase in output and up to 75% reduction in inspection costs by utilizing this combination. The FHWA also encourages Electronic Construction (e-Construction) to minimize delays in project management, store and retrieve documents securely, and increase real-time management (FHWA 2018; Patel et al., 2019; Embacher 2020). By saving 1.78 inspector hours per day and producing/documenting 2.75 times the data, e-Construction could save contractors up to $40,000 per construction project annually (Weisner et al., 2017). PennDOT expects a $23.4 million annual operational savings, including $5.9 million in construction documentation reductions (Brinckerhoff 2017). Paperless inspection and construction administration are two examples of operational savings that can be attributed to a reduction in storage and supply costs. The Florida Department of Transportation (FDOT) standardized its project management, field data collection, and documentation procedures through the use of a customized software platform, tablets, and formal collaborative partnerships. They used e-Construction for all their construction contracts to speed up data collection and handle issues that arise in day-to-day field operations and claim that their $1.1 million investment led to annual savings of $22 million in administrative processing costs (Torres et al., 2018).

e-Ticketing is a novel approach that has been pilot tested by state DOTs since 2015 (FHWA 2021; Sadasivam and Sturgill 2021; Tripathi et al., 2022; FHWA 2022), but only a handful of states have implemented the technology. Many studies have been conducted to investigate its numerous advantages, but they have not measured the increased productivity that results from its use. As this is a strong motivator for stakeholders adopting the technology, the objective of this study is to quantify the increase in productivity of DOT's highway construction inspectors and engineers that results from implementing e-Ticketing technology.

4.3. Literature Review

Decreased productivity in the paper ticketing process: This section focuses on understanding the limitations of the current ticketing process. Producing, sorting, recording, and archiving paper tickets is a time-consuming and expensive process for both state DOTs and general contractors. (Kermanshachi et al., 2019; Sadasivam and Sturgill 2021; Robertson et al., 2022). These documents, which include bills of materials as well as testing reports, inspection records, and a variety of other informational records, are commonly required by contractors and owner's representatives during a project. Since most highway construction work is carried out at the job site, documents must be transferred to computers, demanding re-entry of information, or remain in a bulky difficult-to-access paper format.

The practice of physically collecting delivery truck load codes exposes inspectors to several safety dangers such as walking alongside traffic and boarding trucks to collect paper tickets

(Subramanya et al., 2022). Handing off and entering data through paper tickets is a time-consuming and resource-intensive process that necessitates several "touchpoints" along the way, and the paper tickets lack material traceability since it is not uncommon for them to be lost or damaged, resulting in delayed billing and a waste of considerable time/resources. In contrast, digitally saved data can be retrieved with ease. Illegible data is another concern, as most asphalt plant owners still use dot matrix printers with carbon copies. Despite the recent technological advancements, some DOTs require administrative personnel to manually scan each paper ticket into document management software, which is a time-consuming and repetitive task.

Increased Productivity with e-Ticketing: The FHWA defines e-Ticketing as a software platform that automates the capture and transfer of information for materials as they are moved from the plant to the job site in real time. e-Ticketing is more efficient than a paper-based system because it automates routine tasks such as collecting and summarizing paper tickets and reduces the workload of highway inspectors, enabling them to focus on other inspection tasks (Nipa and Kermanshachi 2019; Subramanya et al., 2022). It also conserves the manpower and resources required for paper printing, storage, and archiving of records, and expedites payment transactions. e-Ticketing streamlines data administration by capturing data electronically and providing opportunities for automatic transfers and archiving documents. It also eliminates lost or damaged tickets, eliminates handoffs involving paper tickets, and automatically creates, transmits, and saves data in a consistent, trustworthy, and efficient manner. Electronic data collection for load deliveries enables safer and more efficient inspections (Sturgill et al., 2019), faster project delivery, more timely payments (Subramanya and Kermanshachi 2022), less effort for ticket management, and real-time comparisons of theoretical and actual tonnage (Nipa and Kermanshachi 2019; Tripathi et al., 2022). Additionally, inspectors' exposure to potentially hazardous working circumstances could be significantly decreased, and contractors' operational efficiency may be increased (Nipa et al., 2019; Subramanya et al., 2022).

4.4. Research Methodology

This study's research methodology consists of four parts, as depicted in Figure 4.1. First, the authors reviewed previous research that was conducted on workforce shortages and the benefits of implementing e-Ticketing technology in highway construction projects. Second, a survey questionnaire was developed to explore ways that inspection staffs' productivity could be improved by implementing e-Ticketing technology. QuestionPro, an online survey platform, was used to construct and distribute the survey to those who had worked in highway/bridge construction projects, and 53 participants completed them. Third, the survey responses from industry professionals were descriptively analyzed to forecast any increase in the inspection staffs' productivity. The following are samples of the survey questions: (1) How frequently does your organization face shortages of inspectors and engineers? (2) What is the average time taken to scan a day's batch of paper tickets into document management software? (3) How many man hours per inspector per day can be saved by adopting e-Ticketing technology? Finally, the survey data and findings from the existing literature were combined to address the industry's workforce shortage.

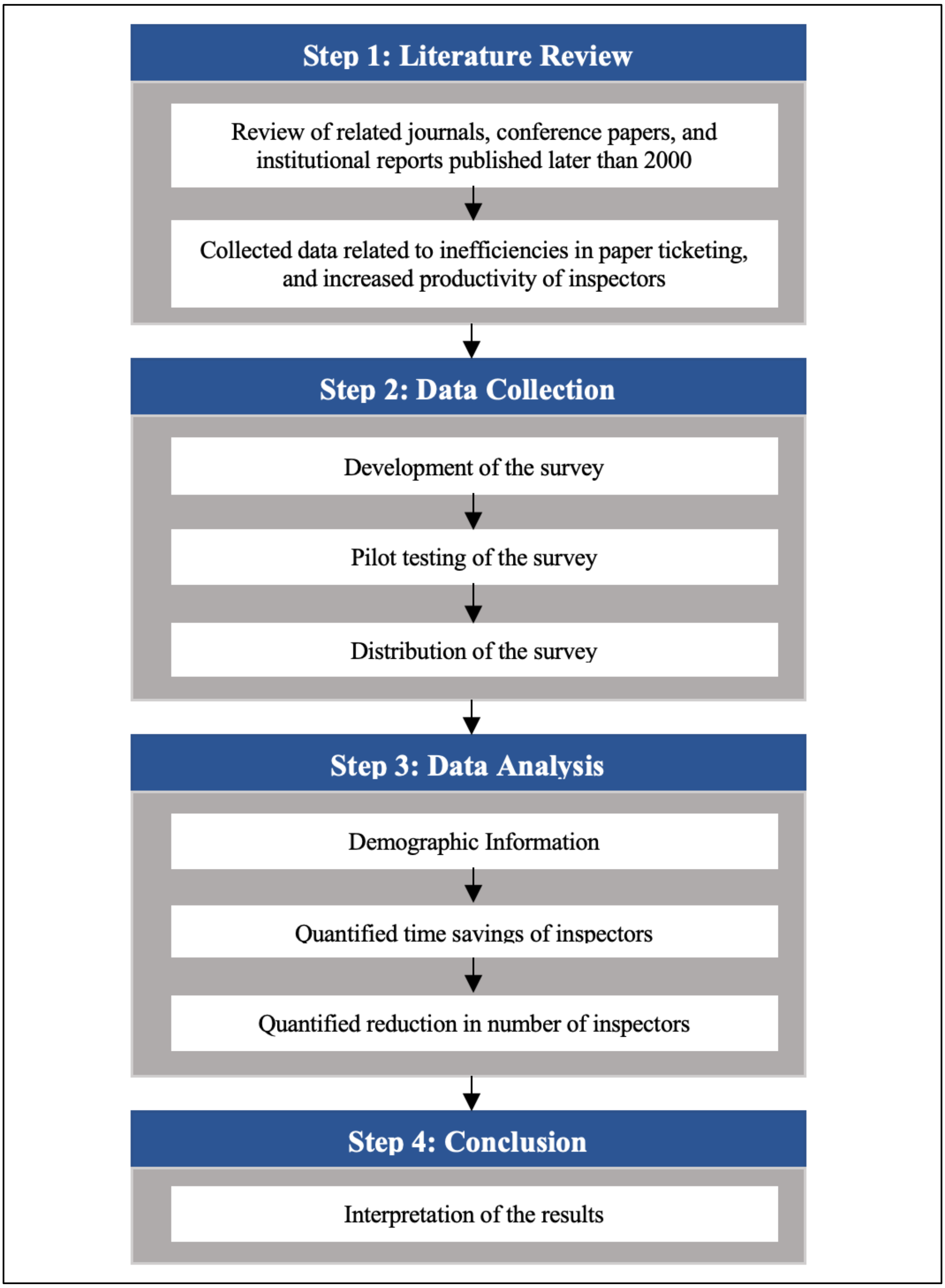

Figure 0-1. Research methodology adopted

Demographics of participants: Of the 53 respondents, 39 respondents had more than 10 years of experience in highway construction projects and 14 had less than 10 years of experience. Hence, the majority of the participants had extensive knowledge of highway construction that would enable them to provide reasonable responses relevant to the current research goals. More than 70% of the respondents were state DOT employees, most of which were from the Indiana and Washington DOTs, although a variety of states at various stages of e-Ticketing adoption were included. Contractors represented 11%, and 5% were material suppliers. More than 75% visited construction sites on a regular basis, while 25% did not. Figure 4.2 illustrates the various DOT participants who responded to the survey. To get more stratified data, the survey was circulated to all the stakeholders involved in implementing e-Ticketing. The survey sample was stratified to better understand the technology's overall implications.

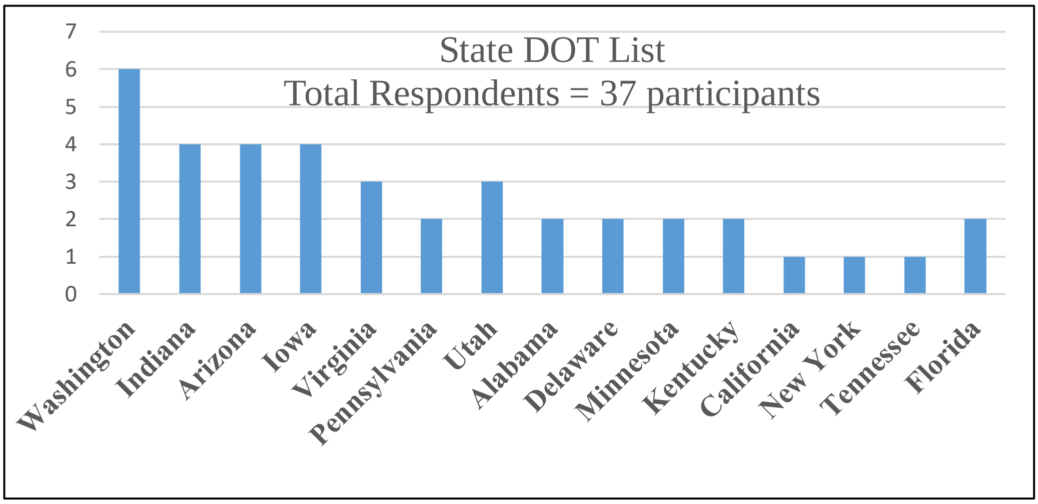

Figure 0-2 Distribution of DOT participants by state

4.5. Results and Analysis

Workforce Shortage of Inspectors and Engineers: The survey questions pertaining to the extent of the shortage of inspectors required responses based on a Likert scale, and 27.45% of the state DOTs indicated a “frequent” workforce shortage, 11.76% responded “All the time,” and 0% of the respondents responded “Never.” This indicates that every state DOT is facing some level of shortage (Figure 4.3).

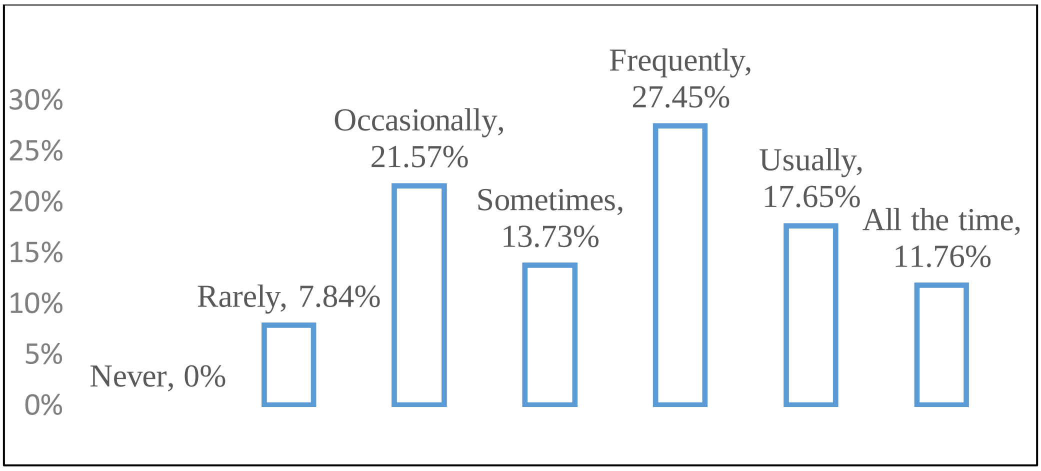

Figure 0-3 Workforce shortage of inspectors and engineers

Productivity Gains: Another question was designed to determine whether implementing e-Ticketing increases inspectors' productivity on job sites or whether the advantage is primarily minimizing human errors. The productivity gains could only be estimated by determining the time required for each step of the paper ticket processing, and 25% of the respondents estimated that it would take them 30 to 60 minutes to manually scan a batch of tickets, 20.9% estimated 1 to 2 hours, 20.9% estimated less than 15 minutes, and a few reported that it would take them 4 hours. A detailed breakdown is shown in Table 4.1.

One of the last steps in manual ticketing is processing the invoices for payment. As per the frequency analysis shown in Table 4.2, this task is also considered time-consuming and was estimated by 24.4% of the respondents to take 30 to 60 minutes; 26.8% estimated that it would take them 15 to 30 minutes. It also should be noted that it is not uncommon for tickets to be lost or misplaced, which delays the billing process.

Table 0-1 Time It Takes Inspectors to Manually Scan One Day's Tickets

Time Taken	Frequency	Percent
Less than 15 minutes	9	20.9
15 - 30 minutes	7	16.3
30 - 60 minutes	12	27.9
1 - 2 hours	9	20.9
2 - 4 hours	4	9.3
4 hours and more	2	4.7

Total	43	100.0

Table 0-2 Time It Takes to Match Up Tickets and Pay Invoices

Time Taken	Frequency	Percent
Less than 15 minutes	8	19.5
15 - 30 minutes	11	26.8
30 - 60 minutes	10	24.4
1 – 2 hours	6	14.6
2 hours and more	6	14.6
Total	41	100.0

Overall, these operations, when combined with inefficiencies in the paper ticketing process identified in the literature review, take more than one hour for many respondents, making the manual system very time-consuming. Respondents were also asked how many hours could be saved by adopting an e-Ticketing system, and Table 4.3 shows that 38.8% of respondents estimated that it would save between 30 minutes and one hour per day, 20.4% estimated 1 or 2 hours, and 24% per cent estimated less than 30 minutes. The varied responses are observed in the dataset as the time saved by inspectors or engineers will differ based on project cost and duration. Also, the state DOTs have different processes for handling the material tickets and the administrative work.

Table 0-3 Time Saved Inspectors per Day by e-Ticketing

Time Taken	Frequency	Percent
30 minutes or less	10	20.4
30 minutes to 1 hour	19	38.8
1 – 2 hours	10	20.4
2 - 3 hours	3	6.1
4 hours or more	7	14.3
Total	49	100.0

Inspector/engineer Requirement: Table 4.4 depicts the difference between the number of inspectors required at a project job site with and without using e-Ticketing and shows that paper ticketing requires more inspectors. The number is obviously the same for both processes for projects that only need only one inspector. Hence the same analysis was conducted after removing the two responses that indicated that only one inspector was needed because of the small size of the project. The corrected percentage of inspectors needed reduces the workforce by approximately 25%. This is also representative of all categories of projects based on various costs in the United States, as it is a subset of the total population and indicates that mandating and implementing the e-Ticketing platform throughout the U.S. could reduce the number of inspectors and engineers needed for highway construction projects by 25%.

Table 0-4 Percentage of Inspectors Saved due to Adoption of e-Ticketing

Criteria	Inspectors required	Mean	Total count
Inspectors needed without adoption of e-Ticketing	99	3.09	32
Inspectors needed with adoption of e-Ticketing	80	2.5	32
Percentage of inspectors saved		23.6%	
Analysis after removal of projects which require a single inspector			
Inspectors needed without adoption of e-Ticketing	97	3.23	30
Inspectors needed with adoption of e-Ticketing	78	2.6	30
Percentage of inspectors saved		24.2%	

4.6. Discussion and Conclusion

The goal of the survey questionnaire was to quantify the effect that e-Ticketing technology would have on inspectors' productivity. The participants estimated that the implementation of an e-Ticketing platform would save each inspector between 30 and 90 minutes per day that would be required for manually scanning paper tickets into document management software, matching them up with the invoices, paying invoices, and calculating cumulative loads manually. From the analysis of the survey responses, it is evident that the productivity of inspectors and engineers is directly proportional to the number of tickets produced at the job site, which is a function of project duration or project cost. The increase in their productivity is directly related to the amount of time saved per day per project by using e-Ticketing technology. The study also investigated whether implementing e-Ticketing can reduce the number of inspectors required for highway construction projects, and it was deduced from Table 4 that for projects that require more than one inspector, e-Ticketing would eliminate approximately 25% of the inspector workforce. In the majority of medium-to-large scale projects not utilizing e-Ticketing technology, one standalone inspector would be needed to collect the paper tickets, record the truck numbers, calculate the cumulative loads, and manually enter the information into Excel spreadsheets. With the adoption of e-Ticketing, this entire repetitive process can be automated, and the inspectors can be reassigned to another project that needs work related to quality control and quality assurance. This in turn helps in minimizing the problem of workforce shortage of inspectors and engineers.

Statewide adoption of e-Ticketing can be of great benefit for organizations coping with dwindling workforces, rising expenses, and delayed schedules. By utilizing e-Ticketing, State DOTs could realize significant savings, and alleviate the nation's chronic workforce shortage of highway construction inspectors. By combining it with other more recent technologies, highly experienced staff and inspectors could serve as a centralized resource to efficiently monitor various highway projects. The widespread adoption of e-Ticketing technology has the potential to delay the retirement of some personnel and by providing rewarding employment in a pleasant, safe, and flexible work environment, entice those who have already retired to return to work part-time. The experienced inspectors can remotely work from the office and monitor the progress of work. Delaying the retirement of inspectors who are passionate about the industry and equipping them with technological advancements will further help in minimizing the problem of workforce shortage. In addition, the e-Ticketing technology will foster storing vast amounts of information such as contract value, project duration, actual cost, actual duration, cumulative tonnage/wastage, inspection checklist data, type of material, project size, number of trucks, number of inspectors, etc., that were previously unavailable and can be used to develop predictive models for cost optimization and quality standards.

CHAPTER 5

ADOPTION OF E-TICKETING TECHNOLOGY IN HIGHWAY CONSTRUCTION: ROADBLOCKS AND RECOMMENDATIONS

Below is a published paper (Chapter 5).

5.1. Abstract

Electronic Ticketing (e-Ticketing) technology has not been widely adopted by the highway construction sector for a variety of reasons, including stakeholders' opposition and technological challenges. Numerous studies have touted its benefits; however, few states have taken the initiative to implement and mandate statewide use of the technology. The objective of this study is to identify the key factors that are preventing the implementation of e-Ticketing technology and to propose appropriate strategies to overcome them. Seven critical limitations that adversely affect its implementation were identified through a thorough literature review, and a survey questionnaire was developed and distributed to key stakeholders in the technology adoption process such as state departments of transportation (DOTs), general contractors, and material suppliers. A statistical analysis of the survey data revealed that problems encountered during the bidding process and the drawing up of agreements, training of employees, and lack of stakeholder support significantly impact the implementation of e-Ticketing technology. In addition, the authors provided practitioners with potential strategies for their consideration when pilot testing and implementing e-Ticketing. The results of this study will aid state DOTs in selecting the most effective e-Ticketing software for pilot testing and will help them overcome obstacles encountered by their predecessors.

Keywords: e-Ticketing, Limitations, DOTs, Highway Construction, Adoption.

5.2. Introduction

State DOTs annually collect thousands of paper tickets that they utilize to verify specifications; prepare invoices; and document the delivery of asphalt, concrete, base course, embankment, and other construction materials. Collecting paper load tickets is an outdated practice. It exposes construction inspectors to a number of safety risks and hazards, as they work among moving machinery, mount the side of vehicles, and wander through high-traffic areas (Kermanshachi et al., 2019; Patel et al., 2020), and requires personnel for collecting, organizing, storing, and archiving the tickets for project management and documentation purposes (Subramanya et al., 2022). If they have not been lost during transmission owing to human negligence, the load tickets are returned to the area office and manually entered into an Excel spreadsheet to calculate daily hauls, summary reports, and process payments. Poor printing may also make it impossible to see the information on the tickets (Nipa et al. 2019). In recent years, transportation agencies have replaced their paper-based ticketing systems with electronic, digital, and paperless e-Ticketing systems, which can improve worker safety by eliminating the need for workers to dodge vehicles in order to obtain paper tickets from truck drivers; increase project efficiency by resulting in faster payment of contractors and subcontractors; and enhance worker productivity by allowing workers to focus on other project-related tasks. e-Ticketing systems are paperless, electronic, and digital, and they do not require any paper tickets (FHWA 2021). e-Ticketing may also be beneficial in asset management due to the fact that information on certain material loads that have been put at particular locations may be taken into consideration when examining variables effecting pavement performance (Subramanya and Kermanshachi 2022). An electronic ticketing system, which is also known as a digital replacement to the conventional ticketing system, is one of the components of an electronic construction system. In place of the laborious and resource-intensive method of project document management that is based on paper, records are collected and kept in an electronic format for the whole of a project. Although e-Construction is a relatively new technology, it has been widely accepted as an upgrade to the construction sector in the United States (FHWA 2021; Nipa et al., 2022). e-Ticketing has a wide array of benefits, yet most states have not yet mandated its use due to reasons that include connectivity issues, inadequate training, high investment cost, and issues relating to data security. The present study aims to analyze the factors that have delayed the implementation of the e-Ticketing platform. Two main objectives have guided this study: (1) identifying the limitations and setbacks in the utilization and rollout of the e-Ticketing platform and (2) determining the strategies that will overcome them.

5.3. Literature Review

Digitization in highway construction: Digitization has suffered significant setbacks in the development of transportation infrastructure projects. Most industries, including manufacturing, entertainment, and services, are finding solutions to quality, safety, and production challenges, resulting in considerable performance and quality improvements (Subramanya and Kermanshachi 2022), but the transportation sector has been slow to accept the changes (Safapour et al., 2020). Highway infrastructure construction has committed major resources to e-Construction in order to eliminate paperwork and automate their everyday operations, and the e-Ticketing component enables the digital transfer of material tickets, such as asphalt and concrete, which account for more than half of construction expenditures. Since the 1990s, while the industry has struggled with technological deployment, scholars have been investigating mobile technology techniques that will reduce the administrative work required for construction field documentation (Bossink 2004).

Concept of e-Ticketing technology: It is time-consuming and labor-intensive for state transportation authorities and the private sector to produce, sort, record, and archive paper tickets (Sadasivam and Sturgill 2021; Subramanya et al., 2022), and collect paper tickets from hauling vehicles exposes construction inspectors and contractor personnel to safety risks (Rouhanizadeh and Kermanshachi 2020). e-Ticketing eliminates the disadvantages of paper tickets by enabling a safer, faster, less resource intensive, more sustainable, and simpler approach through the use of devices and software applications. The ticket data can be transferred in real-time to a cloud or storage system, allowing mobile devices to access it whenever required and creates a single point of data input that can be promptly shared with state DOT information management systems for data mining and payment for materials inspections at the press of a button (Subramanya and Kermanshachi 2022). Due to the fact that raw materials account for more than half of the cost of highway construction, proper tracking and documentation of these items are crucial to the success of current and future projects. Since the first e-Ticketing pilot project in 2015, the number of state transportation agencies that have implemented this technology has increased (FHWA, 2020; Kermanshachi et al., 2021). The Federal Highway Administration (FHWA) has pushed creative and better concepts for planning, constructing, and maintaining highways via the Everyday Counts (EDC) initiative (FHWA 2020) and through this deliberate and planned initiative, has engaged with stakeholders across the country every two years since 2009 to uncover a new set of proven but underutilized solutions. EDC-6 Innovations for 2021-2022, currently in its sixth cycle, is made up of several initiatives, including e-Ticketing, that the FHWA believes would have a positive impact on the industry.

Challenges in the rollout of technology: As a result of the challenges and limitations encountered during pilot testing and attempts to fully adopt the platform, the majority of DOTs are still struggling to fully realize the platform's potential (Subramanya and Kermanshachi 2022). Challenges of e-Ticketing include training employees on new software and hardware, difficulties absorbing and implementing policy and procedural changes, contractor and subcontractor buy-ins to new technologies, and initial investment costs. Despite many state DOTs being aware of the benefits, the aforementioned problems have prevented them from implementing it (Ohio and Iowa DOT 2016).

Covid-19 had a significant influence on the construction transportation business since it was deemed an essential business and was required to function during the lockdowns (Subramanya and Kermanshachi 2021). During this phase, there was a significant shift toward the use of e-Ticketing technology by state DOTs to minimize human interactions and promote social distancing guidelines that would boost worker and operator morale.

The Iowa DOT launched the first e-Ticketing pilot program in 2015, and several DOTs subsequently piloted and/or experimented with the technology, but few have fully implemented it due to a lack of knowledge about how to mitigate the limitations depicted in Table 5.1. Two technologies, e-Ticketing and fleet management have overlapped since the first pilot test was run in IOWA. The two technologies have some overlapping features between them which has resulted in the misconception of the e-Ticketing platform capabilities. The inclusion of GPS transponders and setting up of geofences is the prime feature of fleet management which was pilot tested with e-Ticketing to enhance the software's capabilities. Improper setting of GPS transponders and Geofences are one of the main reasons the stakeholders have decided to disband the pilot tests and to not purchase the software for the entire state.

Table 0-1 Limitations of e-Ticketing Technology

	Limitations	Include or exclude	References
1	High initial investment cost	Include	Brinckerhoff 2017
2	Training of inspectors and engineers	Include	Nipa and Kermanshachi 2019
3	Internet connectivity issues	Include	Nipa and Kermanshachi 2019
4	No standard format for storing data files	Include	Sadasivam and Sturgill 2021
5	Challenges in bidding and agreements	Include	Patel et al., 2019

6	Lack of support and hesitation from stakeholders	Include	Subramanya and Kermanshachi 2022
7	Privacy/security of stored data	Include	Nipa and Kermanshachi 2019
8	Improper setting up of geo-zones	Exclude	Patel et al., 2019
9	Wrong GPS transponders with third party trucking	Exclude	Sturgill et al., 2019

5.4. Research Methodology

The methodology of this research study was comprised of the four steps shown in Figure 5.1. In the first step, a thorough literature search was conducted to identify the limitations and roadblocks associated with the implementation of an e-Ticketing platform. In the second step, the problems and important elements revealed by the literature review were utilized to develop the survey questionnaire, which was designed and distributed using QuestionPro, an online survey platform. The criterion of eligibility was that the participants had to be at least 18 years old and employed by the highway/bridge construction industry. A total of 56 responses were collected and analyzed descriptively and statistically in the third step. In the final step, the results were interpreted and thoroughly discussed. Most of the survey questions required responses on the seven-point Likert scale; a few were multiple choice. Cronbach's Alpha, which yielded a value of 81.9, was established to quantify the internal consistency of the responses. According to George 2003, the following guidelines apply: 0.9 (Excellent), 0.8 (Good), 0.7 (Acceptable), 0.6 (Questionable), 0.5 (Poor), and 0.4 (Poor) (Unacceptable), so the dataset fell under the "Good" category. Likert scale questions do not follow a normal distribution; therefore, the Kruskal Wallis test was adopted, as it compares the medians of different groups to identify statistically significant variations in the data. Some of the questions focused on the demographics of the respondents, such as their years of experience, employer, job title, and place of employment, and the dataset was categorized into two subsets, based on the positions held by the employees. The first subset was categorized as executives who were responsible for implementing the software; the second subset was for inspectors/engineers who lacked in-depth knowledge of the platform. The hypotheses of the study were as follows.

⇒ *Null Hypothesis (Ho)*: There is no significant difference in the limitations of e-Ticketing technology based on employee role in the organization.

⇒ *Alternate Hypothesis (Ha)*: There is a significant difference in the limitations of e-Ticketing technology based on employee role in the organization.

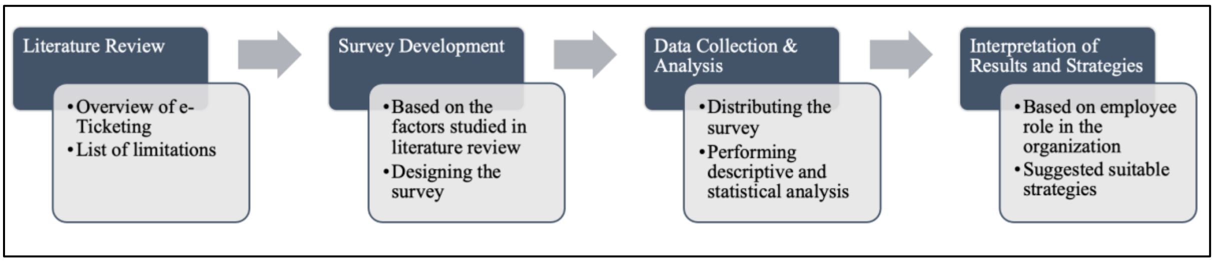

Figure 0-1 Research Methodology

Demographics of participants: Many (35.8%) of the respondents had more than 25 years of experience, while only 9.4% had 5 years or less or 15 to 20 years (Table 5.2). This implies that the participants had a great deal of know-how regarding the construction industry and could be expected to provide credible responses relevant to the current research.

Table 0-2 Years of Experience

	Frequency	Percent	Cumulative%
5 years and below	5	9.4	9.4
5 – 10 years	9	17.0	26.4
10 - 15 years	9	17.0	43.4
15 - 20 years	5	9.4	52.8
20 - 25 years	6	11.3	64.2
Above 25 years	19	35.8	100.0
Total	**53**	**100.0**	

All of those invited to participate in the survey were involved in some way in implementing e-Ticketing. Their employers and their roles in the company organization were noted, as it provided input for analyzing the dataset, based on groups and identifiers. Their responses revealed that 70% worked for state DOTs, 11% were contractors, and 5% worked for material vendors. Of the 70% that worked for DOTs, 25% held executive positions and were responsible for administering the implementation of technology and who had participated in pilot tests or in the implementation process. Project managers, inspectors, and site engineers accounted for approximately 50% of the respondents.

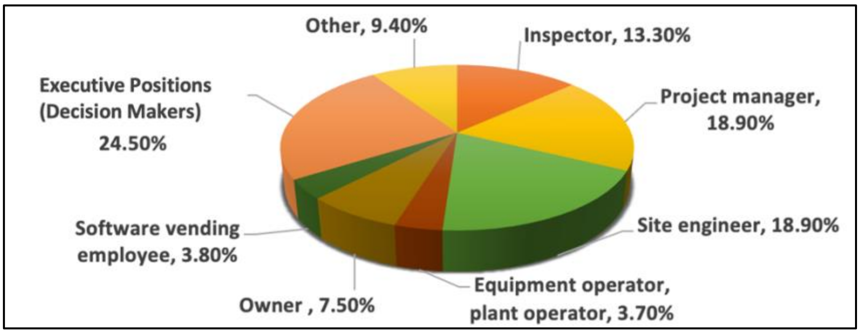

Figure 0-2 Participants' role in the organization

5.5. Results and Analysis

Frequency Analysis of Limitations: The bar chart (Figure 5.3) illustrates the constraints that make it challenging for DOTs and contractors to implement an e-Ticketing system. This research study excluded limitations 8 and 9 (derived from the literature review) in the survey questionnaire, as the primary focus of the paper is to analyze the barriers to implementing e-Ticketing technology and not the overlapping limitations faced in fleet management. Hence, seven barriers extracted from the literature review were included in the survey questionnaire. Respondents indicated their level of agreement with each limitation on a 7-point Likert scale (1- Extremely Disagree and 7- Extremely Agree), and 19.6% of them agreed and 33.9% strongly agreed that the lack of internet accessibility at construction sites is a limitation in the implementation of the e-Ticketing system.

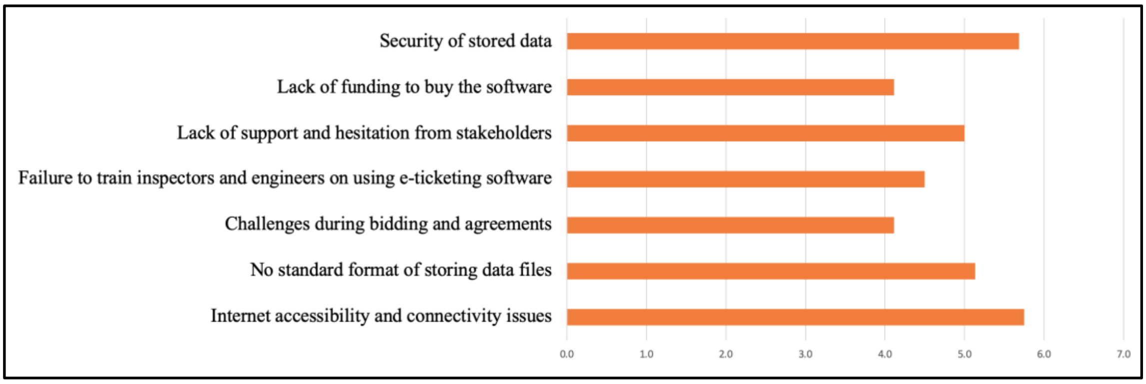

Figure 0-3 Participants' rating of limitations

The overall mean score of 5.683 for the second major limitation, security of the material data (data integrity), places it between "Somewhat Agree" and "Agree," and the next most often cited limitations were "no standardized data files" and "lack of support and hesitation from independent parties." After analyzing the participants' responses, frequencies, and mean scores, the dataset was divided into two groups: (1) Group 1, which consisted of state DOT technology implementation administrators in executive positions such as state construction engineer, director, senior state engineer; and (2) Group 2, which consisted of state DOT inspectors, project managers and site engineers. The two groups were analyzed with the Kruskal Wallis test to reveal the perceptions and understanding of the limitations. The P-values for the challenges were calculated with a 95% level of significance and are shown in Table 5.3, which denotes the significance of each data group and its limitations.

Table 0-3 Results of Kruskal Wallis Test

	Factors/Limitations	P-Values for Limitations based on Technology Administrators Vs Engineers	Null Hypothesis
1.	Internet accessibility at remote locations	0.445	Retain
2.	No standardized format of data files	0.043*	Reject
3.	Challenges in bidding and agreements	0.122	Retain
4.	Failure to train employees how to use the systems	0.432	Retain
5.	Lack of support and hesitation from stakeholders	0.540	Retain

6.	Lack of adequate funding to implement the system	0.046*	Reject
7.	Security of material data (data integrity)	0.002*	Reject

Note: * denotes 95% level of confidence

5.6. Discussion

The results of the survey indicate that the position that stakeholders hold in agencies and companies that construct highway infrastructure greatly influences their perspectives of e-Ticketing. Those who hold executive positions and are technology administrators have a deeper understanding of its benefits and limitations because they were involved in the software's rollout and implementation, and their perspective of the technology is positive. Inspectors/engineers, on the other hand, are the end users and are less knowledgeable, therefore tend to be more negative about implementing the software. After considering the literature, the responses to the survey, and the results of the Kruskal Wallis test, the authors concluded that "no standardized format of storing data files," "lack of funding to buy the software," and "security of stored data" are not major limitations, as the two groups viewed them differently. (See Table 3.) Engineers and inspectors who do not yet comprehend the rollout challenges and scalability of the statewide platform view them as setbacks; the DOT executives have lesser mean score. The researchers analyzed the probable reasons that technology administrators felt that these are not important limitations which hinder the implementation process. The respondents who are not technology administrators such as inspectors, project managers and site engineers have limited knowledge of the e-Ticketing platform and have chosen the limitations in a consistent manner. Whereas the technology administrators who are part of the pilot tests or implementation process have accurately marked the Likert scale and differences which were observed statistically by using Kruskal Wallis test. The probable reasons for the change in perception of the technology and changes to the platform's framework to curb the following limitations are explained below.

No standardized format of data files: Most states do not mandate the use of an e-Ticketing platform; instead, they leave the decision of whether to use a digital ticket transfer method up to the contractor. As a result, contractors use multiple e-Ticketing platforms to receive and store tickets, and when the tickets are transferred to the DOTs in different documentation formats, the technology becomes cumbersome and ineffective. Also, due to Covid-19, a few DOTs have accepted photocopies of tickets through emails/messages which again created a widespread misunderstanding of the capabilities of the platform. Much of this limitation has already been overcome as state DOTs have begun to purchase their own version of the e-Ticketing software that can be accessed by their inspectors, general contractors, and consultants. Some software vendors have released DOT versions of the software that will render application programming interface (API) for material plant integrations This will aid in standardizing the data files and documentation process of the DOTs, saving administrative staff time, and reducing inefficiencies in the paper ticketing process.

Lack of adequate funding: Most pilot projects install Global Positioning System (GPS) transponders in their trucks and employ geofences and geolocations to track their location in real-time. The transponders significantly raise the cost of the investment, and many DOTs do not want to deal with the liability issues that they create. Fortunately, stakeholders are beginning to perceive e-Ticketing and fleet management as two separate technologies, which allows them to utilize the full advantages of one platform's features without paying for software that they don't need or want. Software providers have recognized this problem and are gradually moving away from including GPS transponders and setting up geolocations in their products. State DOTs can save up to 90% of their investment cost if the system they use merely provides ticket source documents with the use of APIs. To ensure a nationwide implementation and rollout, the state DOTs should pilot test the available e-Ticketing software that does not include fleet management functionalities.

Security of Material Data: The DOT's document management software requires access to the e-Ticketing software for directly depositing tickets, and some of them are hesitant about a third-party software vendor holding their ticket data because of privacy and data sharing concerns. To overcome this limitation, the value and functionality of the technology needs to be understood by all the stakeholders in the project. State DOTs have tested a seamless transfer of material tickets into document management software with built-in APIs.

After considering the previous literature and the responses from the survey, the authors concluded that "internet accessibility at remote locations," "challenges in bidding and agreements," "failure to train employees regarding the use of these systems," and "security of material data (data integrity)" have not been dealt accurately by the stakeholders and that is the reason for its persistence and delay in the rollout of the technology since a decade. Based on the above discussion, this study proposes a list of strategies for overcoming the limitations (Table 5.4).

Table 0-4 Strategies for Overcoming Limitations

Significant Limitations	Strategies to overcome limitations
Internet accessibility at remote locations	There are two ways that internet connectivity problems at remote locations can be solved. One is by the inclusion of quick response (QR) codes. (A truck driver could get a QR code that contains the ticket information and share it with the DOT inspector until internet service is restored.) The second solution would be to transfer the ticket information digitally from the truck operator to the inspector through Bluetooth or NFC.
Challenges in bidding and agreements	Several state DOTs have mandated the use of e-Ticketing systems by buying a DOT version of the software, which will help in solving the majority of the problems in process of bidding. As the software will increase the efficiency of all the stakeholders, this problem will eventually be solved with pilot testing and implementation.
Failure to train employees	Virtual meetings and video tutorials, which are available across a variety of applications, could be used to train employees on the e-Ticketing platform. It should also be noted that much of the current workforce is on the brink of retirement, and their replacements are predicted to be more technology savvy.
Lack of support and hesitation	DOTs will have to mandate the use of e-Ticketing software and purchase a version that does not include fleet management to entice the more hesitant

from stakeholders	stakeholders to come on board and incentivize and motivate contractors and small material vendors to begin pilot testing and using the technology,

5.7. Conclusion

Paper-based load delivery tickets are a time-consuming and inefficient method that has been used in highway projects for many years. Automating the operations related to ticketing and the documentation process will save organizations labor costs, increase employee satisfaction, and prevent most safety-related hazards. It will also benefit both transportation authorities and the public by reducing the cost of construction and improving the quality of infrastructures.

This study qualitatively and quantitatively analyzed the challenges of implementing an e-Ticketing platform. The limitations of "internet inaccessibility at remote locations," "challenges in bidding and agreements," "failure to train employees regarding the use of the systems," and "lack of support and hesitation from stakeholders" are significantly affecting the implementation of e-Ticketing technology. The other limitations mentioned in the study have been resolved by proven research and industry innovations. The authors suggest strategies that practitioners can consider utilizing for overcoming all the major roadblocks to the implementation phase while implementing and pilot testing an e-Ticketing platform. This research will also help state DOTs select the e-Ticketing software that best fits their needs and avoid the mistakes and limitations endured by previous users.

CHAPTER 6

BENEFITS OF E-TICKETING IN HIGHWAY CONSTRUCTION AND ITS FUTURE INTEGRATION

Below is a published paper (Chapter 6).

6.1. Abstract

Adoption of technology and digitization have proven to be effective methods for construction inspection and material delivery. Despite the fact that various technologies are available to bolster construction inspection and material delivery, there is a dearth of knowledge on effective utilization of mobile technologies for highway construction. The purpose of this paper is to evaluate the e-Ticketing technology in terms of its advantages and to identify key integrations that will enhance its usefulness. A survey was conducted to determine highway construction stakeholders' opinions on benefits and future integration of e-Ticketing technology. Based on the 53 responses collected from various state DOTs, the study ranked the benefits of e-Ticketing implementation and suggested additional integrations as well. The primary integrations and additional developments for the e-Ticketing platform are automated delivery/dispatch alerts, formattable inspection checklists, fleet management, sensors for temperature monitoring (IR pavers), and as-built drawings/digital blueprints. This study contributes to the existing body of knowledge by examining the opportunities for state DOTs to improve workforce productivity, increase workforce safety and morale, minimize schedule delays, and be prepared for the next pandemic if any.

KEYWORDS: Construction, e-Ticketing, DOT, Inspection, Highway, Digitization.

6.2. Introduction

Mobile devices, software applications, and hardware sensors can provide data collection, sharing services, real-time updates, and the exceptional ability to provide instantaneous responses to requests. With respect to safety, quality and productivity issues, many industries, such as manufacturing sectors, are adopting mobile real-time solutions. Due in part to the rising use of computers, several industries have begun to experience significant performance enhancements. The status of technology advancement varies between sectors. Whereas one industry may view technology as emergent and unique, another industry may describe it as a common/existing technology. Recently, the highway sector has begun to transform its business practices in order to execute projects more effectively (Safapour et al., 2020; Kermanshachi et al., 2021). The Federal Highway Administration and state transportation authorities are embracing e-Construction to minimize paperwork and associated expenses, increase communication and environmental sustainability, and promote more efficient project delivery (FHWA 2020). e-Construction is a delivery procedure for construction management that incorporates a paperless digital administration of all construction documentation by all stakeholders, as well as electronic document routing and approvals (e-signature). The procedure provides mobile distribution and access for all project stakeholders. As a result of its advantages, e-Construction has attracted national attention. e-Construction provides time and cost savings to state departments of transportation (DOT) with increased quality and enhanced data accessibility (Brinckerhoff 2017; Safapour et al. 2018). State DOTs are mainstreaming a multitude of e-Construction system methods and demonstrating substantial returns on investment.

Construction inspectors are directly responsible for collecting and storing vast quantities of information and data from the field (Nipa et al., 2022; Kermanshachi et al., 2019). Obtaining accurate and timely data related to inspection improves the tracking in real-time of project management components such as schedule, cost, and materials (Rouhanizadeh and Kermanshachi 2020; Nipa and Kermanshachi 2022). According to Snow et al. (2013), project inspectors are unable to examine all parts of the project due to a lack of workforce personnel.

The absence of crucial inspection data may have an impact on the project's progress, quality, and budget. This circumstance prompts numerous state transportation agencies to utilize innovative mobile technology for construction inspections (Kermanshachi et al., 2019). Since the early 1990s, technology which includes mobile applications has been prevalent in maintenance and construction projects, enabling construction workers to upload and receive data on the field in a reliable manner (Yamaura and Muench 2018). However, it has been delayed drastically in the highway construction industry because of the lack of proven research regarding the benefits and return on investment. Mobile technologies' current level of practice and field applications are still the subject of limited research. Therefore, the study focuses on identifying the benefits and future innovation of implementing e-Ticketing technology in highway construction projects.

6.3. Literature Review

Benefits of Adopting e-Ticketing: E-tickets are electronic tickets that may be kept on a smartphone or computer and used as proof of entrance or confirmation of a reservation. It can eradicate the obsolete procedure of issuing paper tickets, which prohibits customers and users from modifying and tracking events. To monitor the types and quantities of mix materials, as well as truck arrival and departure times, this system is well-suited for highway construction (Subramanya and Kermanshachi 2022). The concept of electronic transfer of material delivery tickets has been tested by various state DOTs since 2015. e-Ticketing is the digital transfer of material load tickets in real-time using smart devices which has access to the internet. This provides organizations to go paperless and curb the involvement of paper handling at construction sites. The various benefits of implementing e-Ticketing are depicted in Table 6.1 below.

Table 0-1 Benefits of Implementing e-Ticketing

	Benefits	Category	References
1	Day-to-day operations such as ticket handling, calculating cumulative loads and reconciliation will be simplified and semi- automated	Time savings	Patel et al., 2019
2	e-Ticketing can help reduce human-to-human interaction (Covid-19)	Safety	Subramanya et al., 2022
3	Area engineers and resident engineers can monitor multiple projects with ease	Operational efficiency	Nipa et al., 2019
4	Site hazards can be prevented which increases morale of workers	Safety	Subramanya and Kermanshachi 2022
5	All stakeholders can stay connected and informed at the same time regarding project progress	Transparency	Ogunrinde et al., 2020
6	Inspectors can collect, review and document significantly more tickets	Increases productivity	Tripathi et al., 2022

Evolution of e-Ticketing: The deployment of this technology and pilot testing was minimal until the start of Covid-19 pandemic (Subramanya and Kermanshachi 2022; Tummalapudi et al. 2022). Recent epidemic has affected the routine tasks that are carried out by professionals. Organizations have developed ingenious solutions for employees to work from home or in isolated workplaces. Likewise, the highway construction industry accelerated its focus on implementing e-Ticketing technology. Figure 6.1 depicts the different maturity levels of material ticketing process as portrayed by the FHWA (Kermanshachi et al. 2020; Sadasivam and Sturgill 2021). The onset of Covid-19 led to a partial implementation of e-Ticketing platform where the inspectors would receive tickets in the form of image files (Pdf/JPEG). Although image-based files are suitable for electronic transmission and human understanding, the original paper ticket must be given to the project or preserved by the contractor or supplier. Since the image files are unstructured and non-machine-readable data, the information must be retrieved manually and placed into the construction management software used by the DOTs.

The electronic form of ticketing produces comma-separated values (CSV) which are completely readable by computer machines. The next stage involves the transmission of data files through Application Programming Interfaces (API) into state DOTs management software which will further aid in cutting down the administrative work. The final stage of digital object-based data is futuristic and can be achieved through GPS, GIS, Building Information Modelling (BIM) and integrating other emerging technologies into the e-Ticketing platform.

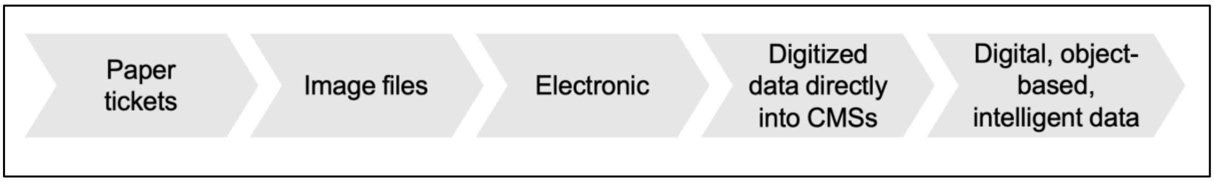

Figure 0-1 Evolution of e-Ticketing Source: (Sadasivam and Sturgil 2021)

Integration of e-Ticketing: e-Ticketing data may be combined with various other technologies such as intelligent compaction (IC), artificially intelligent sensors, and infrared pavers, which reduces the overall number of man-hours and the duration of the project. An increase in equipment usage and the raw material is directly connected to project growth. Adding new and current technologies to the e-Ticketing platform may open up a number of new avenues for asphalt paving and construction material distribution. (Subramanya and Kermanshachi, 2022). Many transportation organizations and state DOTs are automating their material delivery and highway paving process with enhanced imaging, infrared sensors, automated UAV surveying and inspection, and intelligent compaction (Li and Liu 2019). The integration of these cutting-edge advancements into the e-Ticketing technology can yield substantial benefits to owners and contractors. For the purpose of assessing project progress and determining geometric model conformance, automated drones may be utilized in combination with 4D-BIM models and digital as-builts. Remote construction project monitoring, end-user requirements application/verification, construction education, and team communication may all benefit from emerging technology. When coupled with IC-enabled pavers, drone surveys, thermal profilers, and enhanced imagery, the platform's applications and utilization rise tremendously (Subramanya et al., 2022). Highway construction inspectors can replace handheld IR thermal cameras with paver-mounted thermal profilers that monitor the whole mat's temperature in real-time. An IR temperature monitoring device may be mounted on the paver's back end to keep track of the mat's temperature as the project progresses. It is possible to use IC technology to improve quality control during the compaction phase of paving projects and to combine live feed from distant locations into the e-Ticketing platform. To make daily operations more efficient, new technologies may be introduced into the ticketing platform. Also, e-Ticketing and other developing technologies can automate and simplify numerous tasks and activities conducted during paving operations.

6.4. Research Methodology

The study's goal was achieved using the research approach shown in Figure 6.2. The research methodology is conducted in three phases namely, (1) Extensive review of available literature; (2) Survey development and distribution; and (3) Ranking benefits and future integration from survey responses. In phase 1, conference papers, journal publications and institutional reports were reviewed to identify present technological trends related to e-Ticketing and their future integration. In the second phase, a survey questionnaire was developed and distributed online. A total of 53 completed responses were collected from survey participants. In the third phase, the collected responses relating to benefits and integration of technology was ranked using the Likert scale data.

Figure 0-2 Research methodology

The survey questionnaire recorded participants' experience to obtain a reliable data. 36% of respondents had more than 25 years of experience while 9.4 percent had between 5 and 15 years of experience as shown in Figure 6.3. It can be understood that the participants had extensive knowledge of the construction business and could be relied upon to deliver trustworthy comments pertinent to the present study.

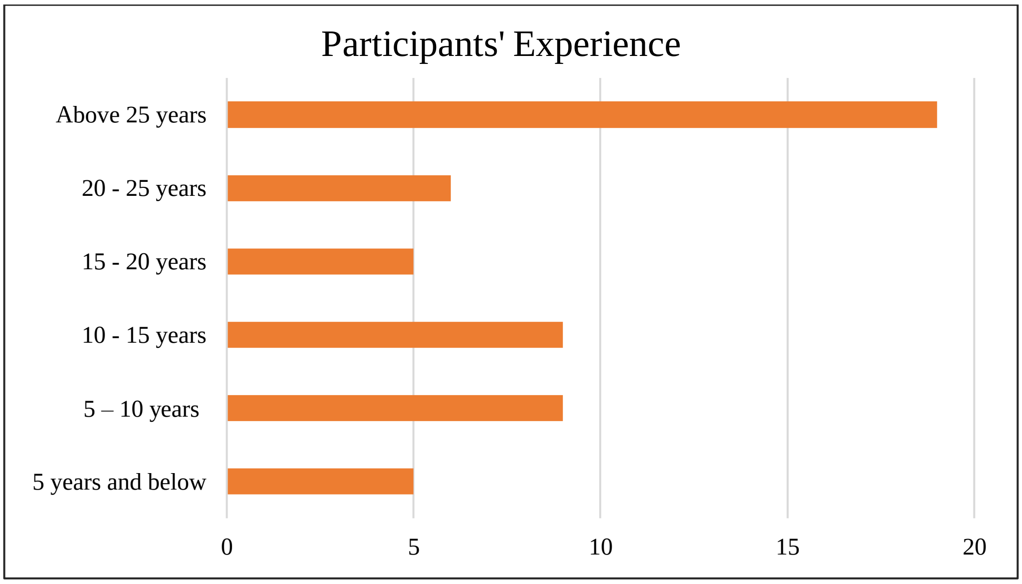

Figure 0-3 Participants' years of experience

6.5. Results and Analysis

There are a variety of benefits to implementing e-Ticketing technology such as increased productivity, time savings from automating administrative processes, increased safety of inspectors and increased operational efficiency. The benefits which were derived from the review of literature were framed into 7-point Likert scale questions. As seen in Figure 6.4, the majority of the participants have indicated that they either "Agree" or "Strongly Agree" with the benefits of e-Ticketing technology. Interestingly, a few respondents indicated that they disagree with the benefits of the technology.

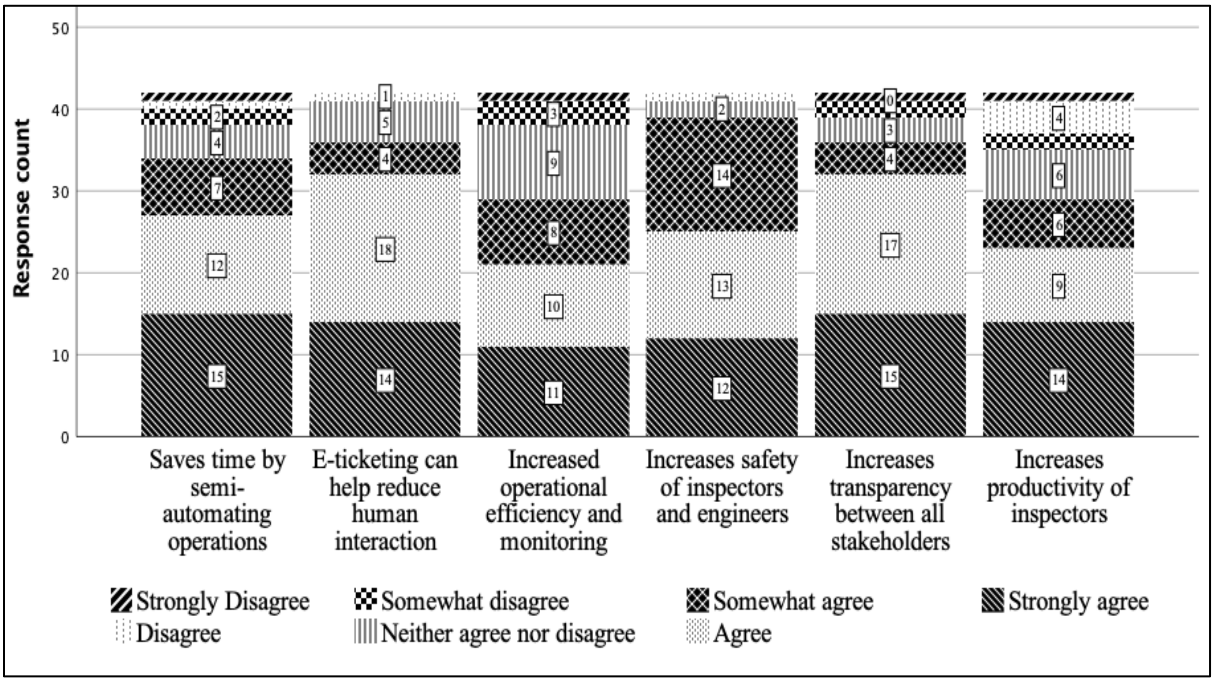

Figure 0-4 Participants response to benefits of e-Ticketing

Furthermore, the benefits of implementing e-Ticketing platform were ranked by the authors depending on the survey responses. The ranking was given based on the total weighted mean scores from the available Likert scale data. The benefits are directly related to time savings, social distancing, operational efficiency, safety of inspectors and engineers, transparency, and productivity. The seven-point Likert scale (1 being strongly disagree and 7 being strongly agree) was used to get the mean score for each advantage, which was then compared to establish the relative ranking of distinct benefits in descending order of significance. The following Table 6.2 depicts the ranking of benefits. Increased transparency, time savings and increased productivity has been ranked the highest by the respondents. It is important to note that increase in safety of inspectors and engineers has been ranked the least comparing to the increase in safety due to social distancing guidelines.

Table 0-2 Ranking benefits of implementing e-Ticketing

Rank	Benefit category	Mean Score
1	Increases transparency and cross-functional collaboration	6.2
2	Saves time by semi-automating day-to-day operations	6.1
3	Increases productivity of inspectors and engineers	6.1
4	Promotes social distancing guidelines	5.9
5	Increases monitoring and operational efficiency	5.6
6	Reduces hazardous zones and increases safety of workers	5.4

The survey also aimed to collect participants' responses related to the integration of emerging technologies with e-Ticketing. Various technologies derived from the existing literature were included into a Likert scale questionnaire relating to the importance of each technology with respect to integration. The following Figure 6.5 depicts the various responses.

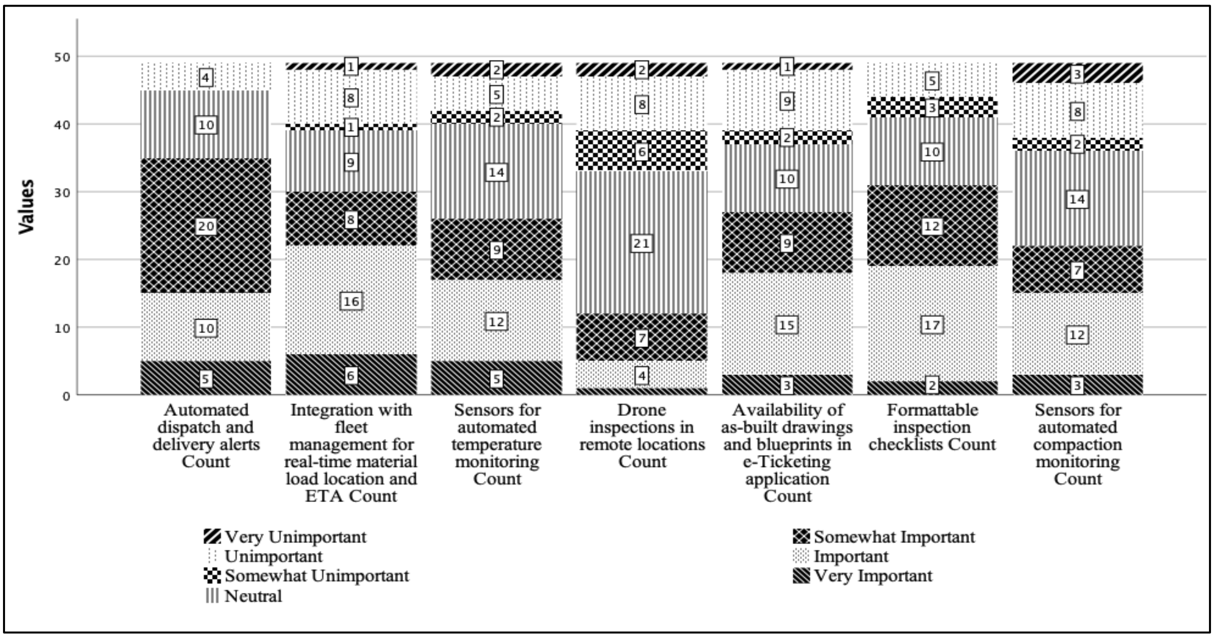

Figure 0-5 Participants' response to e-Ticketing integration with emerging technologies

The responses related to the integration of technologies have varied perceptions as seen in the above figure. Integration with fleet management and formattable inspection checklist has been marked as highest level of importance from the basic visualization of the chart. Drone inspections have been marked the highest in terms of neutrality of responses as the participants do not have prior knowledge of technology's utilization and benefits. To fully comprehend the level of significance of these technologies and prioritize pilot testing for integrations, the study has ranked the technologies. The ranking is based on the mean scores obtained from the Likert scale responses.

Table 0-3 Ranking future integration of e-Ticketing platform

	Benefit category	Mean Score	Rank
1	Automated dispatch and delivery alerts	5.96	1
2	Formattable inspection checklist	4.82	2
3	Integration with fleet management	4.78	3
4	Sensors for temperature monitoring (IR pavers)	4.61	4
5	As-built drawings and digital blueprints	4.5	5
6	Intelligent compaction	4.27	6
7	Drone inspections and monitoring	3.8	7

6.6. Discussion

Transparency and cross-functional collaboration are two of the most significant advantages of e-Ticketing. As highway projects include a variety of stakeholders such as state DOTs as owners, general contractors, subcontractors, material suppliers, inspection agencies/consultants, and third-party trucking agencies. It is vital that all stakeholders are connected and be informed simultaneously so that there are no communication gaps which may lead to disputes and schedule delays.

It is obvious that minimizing schedule delays will increase the efficiency of the overall project which would be advantageous to all the stakeholders. Most of the repetitive tasks performed on the field such as collecting paper tickets from operators, calculating cumulative loads, recording truck numbers, verifying tonnage, and reconciling tickets can be easily semi-automated which would save significant time. The time saved by inspectors and engineers can be used for more critical tasks such as quality control which will aid in increasing the performance of highways. The increase in productivity of inspectors has been ranked third. It is important to note that there is a chronic shortage of workforce in highway construction.

Technologies such as e-Ticketing which can increase the productivity of inspection staff should be mandated and implemented state-wide which can aid in overcoming the workforce shortage. The next benefit is related to promoting social distancing guidelines as the technology will reduce human-to-human interaction. It was also observed in the previous studies that e-Ticketing technology had an increased adoption rate at the time of peak Covid-19. It is crucial that the construction industry should be prepared for any future pandemic outbreaks.

Another benefit is related to increased efficiency in monitoring which proves to be beneficial for area and district engineers. The area engineers can assign inspectors based on the need and can track multiple project progress remotely. The safety of inspectors and engineers is ranked last as opposed to the previous studies which have mainly focused on the safety of workers. Although there are very few incidents of hazards and accidents while collecting paper tickets, any technology which facilitates the safety of the workforce should be taken into serious account.

Recent innovations in the telecommunications sector, such as remote networking, 5th generation broadcast connection, and the dramatic rise in data rates can aid the construction industry in acquiring real-time data. The deployment of 5G-enabled towers enables an entirely new set of systems to assist machines, humans, and inanimate things. From the survey responses, it was evident that automated dispatch and delivery alerts are one of the most important integrations. This can be achieved by bringing the third-party trucking agencies and operators on-board. The dispatch and delivery alerts can help inspectors monitor the work more effectively on large sized projects.

6.7. Conclusion

Almost every industry utilizes digital technology to speed up operations, reduce paperwork, limit manual labor, and lower overall expenses. Companies in the construction industry are beginning to recognize the benefits of incorporating advanced technologies into their daily operations. Independent technology, such as e-Ticketing, offers numerous advantages and the study focused on the benefits of implementing the same. The study's ranking of benefits will aid stakeholders such that the top four advantages of e-Ticketing are increased transparency, time savings, increased productivity, and reduced workforce. Additionally, they serve as an effective tool for creating semi-automated inspections, real-time data collection, and cost reduction. e-Ticketing software is beneficial for all project stakeholders because it significantly increases communication, transparency and operations while speeding up project delivery. The responses to the survey indicated that automated dispatch alerts, formattable inspection checklists, fleet management, infrared pavers, and digital as-builts are perceived as technologies that add value to e-Ticketing integration. The integrated platform will allow agencies to deploy highly experienced inspectors and engineers as a centralized source capable of monitoring multiple highway projects efficiently without travel. In addition, it generates vast quantities of previously difficult-to-assemble project data, such as contract cost, inspection checklist data, contract duration, actual duration, actual cost, project size, cumulative wastage, number of trucks, type of material, number of inspectors, etc.

CHAPTER 7

EVALUATION OF OPERATIONAL CHALLENGES IN HIGHWAY CONSTRUCTION MATERIAL DELIVERY

Below is a published paper (Chapter 7).

7.1. Abstract

One out of every five miles of highways and 45,000 bridges in the United States are in poor condition. Transportation agencies and highway construction industries are significantly impacted by workforce shortage, quality issues, and schedule delays for decades. For almost two decades, the industry has been facing the same obstacles and it is high time that these problems are addressed with research, innovation, and implementation. This study's objectives are to: (1) identify the various inefficiencies in material delivery, ticketing, and inspection processes; (2) rank the challenges to analyze their impact; and (3) identify proven technologies that can mitigate the encountered challenges. The study involved a comprehensive review of literature before distributing a survey questionnaire to 20 state departments of transportation (DOTs). Using the Relative Importance Index (RII), the authors have ranked the operational challenges in highway construction. According to the findings of the study, the primary challenge in highway construction is the shortage of field engineers and inspectors. This research will encourage state DOTs to implement digital delivery and inspection technologies. Utilizing electronic ticketing and electronic inspection will eliminate some of the challenges and assist in mitigating the rest.

KEYWORDS: Highway, Technology, Challenges, Innovation, Workforce.

7.2. Introduction

Highways are a crucial component of transportation networks as they facilitate economic and social growth, promote territorial integrity, and facilitate the mobility of people and goods

(Kermanshachi et al., 2019). Construction projects cannot be totally separated from time and cost concerns, which frequently jeopardize project completion. Transportation projects involve complex and multilayered supplier networks, which necessitates the monitoring of several planning and implementation activities (Safapour et al., 2019). Seventy-six per cent of construction projects have resulted in cost overruns that exceeded the baseline estimate (Mahamid and Bruland 2011). When financial pressure increases, stakeholders often develop skepticism between the Return on Investment (ROI) and the progress of projects, leading to project schedule interruptions, unpaid invoices, and an increased risk of abandoning the whole construction plan (Kermanshachi et al., 2019). With highway construction delivery, the government entities cannot terminate or halt the project and must continue to expend budget and manpower to complete the project. The spectrum of planning, design, management and construction operations that constitute repair or reconstruction is included in highway projects. The duration of a highway construction project encompasses all of these operations. Although it is possible to reduce the duration of each project activity, the greatest advantages will be obtained during construction operations on the field. These advantages include decreased traffic delay and associated expenses, fewer crashes and injuries connected with construction-related incidents, reduced capital expenditures, increased morale of workers, and increased productivity of engineers/inspectors.

It is said that highway construction in and of itself is critical to managing as it requires long-distance and spread logistical strategies coupled with rigorous timelines (Safapour et al., 2019). Each passing day of delay would exponentially escalate the incurred cost of materials, labor, and utilities. In the context of a multi-tiered third-party system, the traditional management strategy of overall quality management often fails to generate adequate outcomes. Much consideration must be devoted to project timelines as was previously given to project budgets (Nipa et al., 2019). The introduction of novel management, design, construction techniques and technology would lower the project durations. Highway authorities and design consultants should pursue and apply these methods. There are several challenges faced by stakeholders in day-to-day activities related to highway construction material delivery. One of the key purposes of the present study is to identify the challenges and limitations faced by highway construction professionals especially organizational and operational difficulties. The focus is primarily on material delivery as more than 50% of the project cost is directly related to the materials procured in highway construction. The rate and efficiency at which the materials are used and deployed is directly related to project success. The study's objective also focuses on identifying technological advancements in the material delivery of asphalt and concrete which will help in minimizing the problems and challenges faced in highway construction.

7.3. Literature Review

Operational Challenges in Material Delivery and Ticketing: Producing, recording, sorting, and documenting paper tickets is an expensive and time-consuming process for state DOTs and general contractors alike. (Kermanshachi et al., 2019; Sadasivam and Sturgill 2021). During a project, contractors and owner's representatives typically require documents such as material bills, inspection records, test reports, and other information-based records (Subramanya and Kermanshachi 2022). Since the majority of highway construction work is performed on-site, papers must be moved to computers, which requires re-entry of data points, or kept in a cumbersome, inaccessible paper format. The physical collection of delivery truckload tickets exposes field inspectors to a number of safety risks including walking past traffic and boarding trucks to gather paper tickets (Subramanya et al., 2022). Since the majority of asphalt plant owners continue to utilize dot matrix printers with carbon copies, the paper-based documents are illegible.

Despite recent technology developments, few DOTs require their administrative staffs to manually scan each paper ticket into document management software, which is a tedious and time-consuming repetitive process (Subramanya and Kermanshachi 2022). A material ticket is necessary for the delivery of materials to a state DOT project. Typically, material records are produced, transmitted, authorized, documented, and stored beginning with the material source and continue throughout the delivery process. These documents are needed to keep track of purchased material and to pay the contractor along with trucking companies and material suppliers. These records are also utilized to wrap up a project, becoming a part of the project's final construction record.

In present procedures by DOTs, paper-based forms and tickets are extensively used. Any amendments and change orders in projects involving numerous parties would often result in burdensome procedures. Due to the manual nature of the process and the need for layers of scrutiny on the data, generating the material records daily becomes a time-consuming job. As a result, an automated method might greatly improve data quality while also considerably altering and benefiting the material delivery process.

Organizational Challenges in Highway Construction: The transportation sector has several challenges, such as a lack of experienced personnel and other kinds of workers, problems with the final quality of projects, document management, injuries/fatalities, cost overruns, and schedule delays (Kermanshachi et al., 2017). In comparison to ten years earlier, the National Cooperative Highway Research Program (NCHRP) reports that "DOTs are managing bigger highway networks with fewer in-house employees." According to research by Taylor and Maloney, between 2000 and 2010, the number of state-managed roadways rose by 4.10 percent, but the number of full-time equivalent personnel fell by 9.68 per cent, indicating a significant labor shortage among the 40 state DOTs used as the study's basis. According to Vidalis and Najafi (2002), the majority of construction projects experience cost and schedule overruns, which can result in construction costs going over budget and project delays. These overruns can be brought on by weather-related damage, utility costs, delays in material delivery, quality problems, and material reconciliation. Most transportation infrastructure projects suffer from cost overruns, timetable delays, and quality problems, and inspectors and project engineers are in limited supply in rural and isolated locations. According to a statement from the White House, 45,000 bridges and one out of every five miles of highways and key roads are in poor condition (The Bipartisan Infrastructure Deal, The White House 2022). Before the US infrastructure catches up to that of nations like China and Japan, according to the American Society of Engineers (ASCE), a $2.6 trillion investment deficit must be closed (Siripurapu, 2021). The US Department of Transportation (USDOT) has set aside $53 billion for fiscal year 2022 to improve roads, and the US DOT and the Federal Highway Administration jointly announced $27 billion in financing. President Biden's $1.2 trillion infrastructure plan will support surface transportation programs for an additional five years. It is encouraging to see that this historic infrastructure drive is taking use of new technologies. In order to accelerate the use of construction technologies like digital twins, e-Ticketing, as-builts, and many more, the infrastructure bill allocates $100 million over the course of five years. Retirements, the inability to retain brilliant workers, greater industry competitiveness, and the prospect of working in hazardous or isolated places have all contributed to the decline in the workforce (Subramanya et al., 2022). While other businesses, including those in the manufacturing sector, have embraced advanced technical trends, upgraded their legacy systems, and created advanced innovations, the construction sector has been slow to accept both established and developing creative procedures (Nipa et al., 2019; Subramanya and Kermanshachi 2020).

Digitalization in Highway Construction: The construction progress is very much dependent on basic resources such as materials, labor, equipment, tools, information and capital. This has a direct impact on the construction method, techniques employed, and sequencing of various activities. Emerging e-Construction technologies facilitate access to live feed of data and provide more precise data collecting methods. In addition, these technologies give inspectors and engineers with access to a vast choice of field-friendly solutions. As an example, technologies are often used to input and monitor inspection data, record field activities in the construction management system, to access plan sets and manuals, and connect office staff to the field (Nipa et al., 2022). Most modern construction technology may be broken down into three distinct levels: (1) conventional paper-based procedures, (2) intermediate paper-based/electronic ways (Mixed approach), or (3) an advanced paperless/electronic process (Mallela et al. 2018). Shah et al. (2017) studied the maturity levels of state DOTs in the United States and found that they varied from nascent to advance in terms of maturity. According to a study of 26 respondents, 12 per cent of DOTs are in the early stages, 80 per cent are in the middle stage, and only 8 per cent are mature. Because of this, highway construction projects will need to use new e-inspection methods in place of the manual ones now used by the DOT. The ongoing dependency on paper-based inspections and ticketing hinders innovation, while a lack of skilled personnel slows production rates and lowers the quality of the highway infrastructure (Taylor and Maloney, 2013). Thus, a growing number of DOTs are searching for ways to increase efficiency and optimize their inspection resources. A reduction in inspection staff may be possible even though construction is a very physically demanding industry. Effective techniques to infuse the use of advanced automation and e-construction may minimize the demand for construction employees, enhance productivity by an average 8 per cent, and cut costs by up to 5 per cent according to Harper et al. (2019). According to Harper et al. (2019), the rate of digitalization in the construction sector correlates directly with productivity increases.

7.4. Research Methodology

The present study conducted a comprehensive literature review in order to summarize the available wealth of knowledge, identify research needs, and record the major findings of previous relevant studies. Specifically, the significant challenges in the material delivery and inspection processes for highway construction were documented. In addition, a survey was conducted and distributed using the online QuestionPro platform. The survey contained information regarding the participants' demographics and the frequency of difficulties they encountered in highway construction. A total of 1100 participants' email addresses from various state DOTs, general contractors, and material suppliers were collected for the survey. 53 credible, complete responses have been received which were used for the analysis. Using the Relative Importance Index, the survey responses were summarized and ranked using the Relative Importance Index (RII). Later, the authors suggested technologies from the literature that will aid in eliminating or mitigating the obstacles encountered. Figure 7.1 below depicts the overall research methodology adopted for the study.

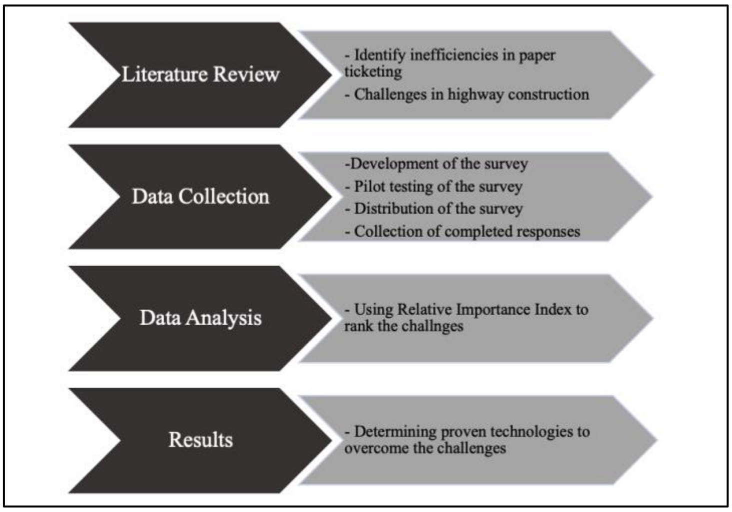

Figure 0-1 Research Methodology

To define the study's sample size, demographic characteristics relating to respondents' language, region, experience in the construction industry, and job position are inquired.

Consequently, frequency analysis reveals that all the construction workers are English-speaking respondents. In terms of experience years of participants, approximately 75% of the respondents have more than 10 years of experience and 35% have more than more than 25 years of experience in highway construction industry (Table 7.1). This indicates that participants have extensive knowledge of the construction industry and can therefore provide credible responses pertinent to the current study.

Table 0-1 Experience years of participants

Experience Years	Frequency	Percent	Cumulative Percent
5 years and below	5	9.4	9.4
5 – 10 years	9	17.0	26.4
10 - 15 years	9	17.0	43.4
15 - 20 years	5	9.4	52.8
20 - 25 years	6	11.3	64.2
Above 25 years	19	35.8	100.0
Total	**53**	**100.0**	

7.5. Results

The first research question aimed at examining the main problems and issues pertaining to the paper-ticketing systems, which are a part of day-to-day highway construction operations. In this regard, the existing literature helped to highlight that since the paper-ticketing system is more manual and labour-intensive, it is often subjected to errors in reconciliation, errors in maintaining accurate records with a single entry, faults with sending the wrong tickets, misplacing the paper tickets, recording inaccurate ETA of material delivery, etc. Taking note of these challenges, the respondents were asked to rate on a 7-pointer Likert scale how often their organizations experience such issues and errors. Figure 7.2 shows the response count of each issue in the respondents' organization.

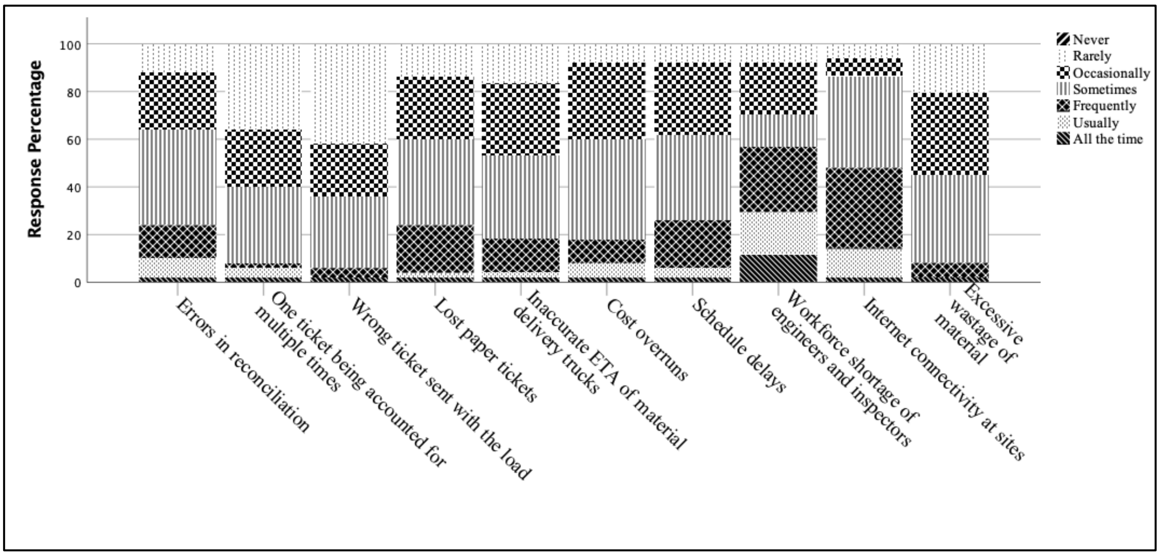

Figure 0-2 Response percentage of participants regarding challenges

Using Relative Importance Index (RII), the study has further assessed the constraints in highway construction material supply by ranking them. On a seven-point Likert scale, problems in highway construction were scored from 1 (Never) to 7 (All the time). The authors have utilized RII to rank the issues. The below formula was used to calculate the RII. The value ranges between 0 and 1. Chen et al. (2010) presented the RII, and its importance level as determined by transformation matrix. The significance levels are determined by the following criteria.

$$\text{RII} = \frac{\Sigma W}{A \times N} \qquad (1)$$

In the above equation (1), “W” shows the weight of any variable determine by the participants, “A” represents the highest value of scale (weight), and “N” shows the number of respondents. Table 7.2 depicts the categories and its respective range of the RII.

Table 0-2 Range of Relative Importance Index

Category	Range
High	0.8 < RII < 1.0
High-Medium	0.6 < RII < 0.8
Medium	0.4 < RII < 0.6
Medium-Low	0.2 < RII < 0.4
Low	0.0 < RII < 0.2

The ranks and their respective weights are displayed in Table 3. Only two challenges for highway construction were identified as having a "High-Medium" relevance level, while all other problems have a "Medium" importance level. In highway building, the shortage of engineers and inspectors has the highest priority, whereas sending the wrong ticket with the load is deemed a minor issue.

Table 0-3 Ranking of challenges using RII

Variables	RII	Ranking	Importance
Workforce shortage of engineers and inspectors	0.658	1	H-M
Internet connectivity at sites	0.621	2	H-M
Errors in reconciliation	0.543	3	M
Schedule delays	0.543	3	M
Cost overruns	0.532	4	M
Lost paper tickets	0.526	5	M
Errors in cumulative tonnage	0.518	6	M
Inaccurate ETA of material delivery trucks	0.495	7	M
Excessive wastage of material	0.462	8	M
One ticket being accounted for multiple times	0.448	9	M
Wrong ticket sent with the load	0.425	10	M

7.6. Discussion

To gain a better knowledge of the need for technology adoption in highway construction material delivery, the researchers surveyed participants about the main challenges they encounter when working on highway construction projects. Table 7.3 presents the RII for the collected responses. It can be observed that workforce shortage of engineers and inspectors is ranked the highest importance. Due to the nature of highway construction activities as discussed in the literature review section, the sector should bolster its existing employees by implementing technological advancements and trends in material delivery and supply. The second most common challenge is the problem of internet connectivity at highway sites which are usually in remote locations. The inaccessibility of internet will render enormous problems related to data and specification retrieval which might lead to quality issues. It was surprising to notice that errors in reconciliation and schedule delays have been ranked the same by the respondents and hence share the third rank of importance related to challenges.

The various advantages of technology integration and automation may be utilized to handle current problems and semi-automate or simplify construction operations' daily tasks. Given the massive investment in highway building (Infrastructure bill) and the dearth of inspectors, it is past time for state DOTs and other agencies to adopt productive and efficient construction techniques. In order to deliver cost-effective, safe, and dependable products and services, the building of transportation infrastructure must keep pace with global technology breakthroughs. The Covid-19 pandemic accelerated the growth of a few technologies; proposed technologies such as e-Ticketing, fleet management, and digital as-builts have garnered national attention and offer immense potential for advancement and innovation; and more DOTs and private companies have begun adopting technologies (Subramanya and Kermanshachi 2021). Modern construction companies are embracing collaborative technologies such as real-time, cloud-based analytics to mine massive structured and unstructured data archives and to ensure that all involved stakeholders are on the same page and briefed with real-time data. These technologies, by virtue of their revolutionary benefits, have the potential to revolutionize the highway construction sector.

Producing, sorting, recording, and archiving paper tickets is costly, laborious, and time-consuming for both state transportation authorities and the private sector (Sadasivam and Sturgill 2021). Construction inspectors and contractor personnel are also exposed to safety-related risks while collecting paper tickets from hauling trucks (Rouhanizadeh and Kermanshachi 2020; Nipa et al., 2022). e-Ticketing solves the shortcomings of paper tickets by delivering a safer, faster, less resource-intensive, more sustainable, and simpler process. e-Ticketing data may be sent in real-time to a cloud or storage system, enabling mobile devices to access it whenever necessary. It creates a single source of data input that can be promptly shared with the document management systems of state DOTs for data mining and one-click payment for materials inspections (Subramanya and Kermanshachi 2021). In the development of highway infrastructure, raw materials account for more than fifty percent of the total project cost; thus, proper monitoring and recording of these tickets are crucial for the success of ongoing and future projects (Kermanshachi et al., 2018). The implementation of e-Ticketing will help in nullifying errors in reconciliation (Rank 3), lost paper tickets (Rank 5), errors in cumulative tonnage (Rank 6), one ticket accounted multiple times (Rank 9), and wrong ticket sent with the load (Rank 10). Implementation of this technology will aid in automating the majority of the aforementioned obstacles, hence streamlining processes. In addition, from the standpoint of contractors, when e-Ticketing technology is coupled with GPS transponders, it will provide precise ETA for material delivery vehicles, hence improving daily site operations. One of the greatest benefits of this technology is that it boosts the efficiency of the workforce (Tripathi et al., 2022), which will help reduce the shortage of inspectors (Rank 1) because the current personnel will be boosted by technological improvements that simplify their operations. The introduction of QR codes can help in mitigating the problem of internet connectivity (Rank 2) at highway construction sites in terms of digital ticket transfers. When the engineers and inspectors are handed mobile tablets which can store all the specifications, plans and designs along with digital ticket transfer with QR codes, the problems of internet connectivity will be drastically reduced.

Highway infrastructure's long-term performance and quality are contingent upon construction inspection. State DOTs' existing method of construction inspection is subjective, error-prone, and time-consuming since inspectors must manually collect and interpret required specifications in a paper-based format. Cloud-based inspection apps may generate customized digital checklists, aid in maintaining daily progress reports, and guarantee that everyone has a comprehensive perspective of the project's progress, hence reducing the likelihood of errors. Agencies and departments have encountered a scarcity of experienced inspectors in recent years owing to retirements, personnel reductions, and resignations of individuals seeking private sector employment (Embacher 2021). It is crucial to preserve and manage the acquired knowledge of construction inspection (what, when, and how to examine) and to incorporate this information into the daily construction operations. When electronic inspection technologies are integrated with e-Ticketing, it can significantly reduce quality issues. The reduction of quality disputes and reworks associated with them will drastically reduce cost overruns and schedule delays faced in the construction of highway infrastructure (Kermanshachi et al., 2020).

7.7. Conclusion

The study’s findings suggest that the workforce shortage of inspectors and engineers is one of the major problems in the highway construction sector. This effect will have a domino effect on the quality, cost and schedule-related issues which can affect the public. State Departments of Transportation (DOTs) and other agencies are spending colossal amounts from the infrastructure bill to construct and maintain roads and bridges, therefore it's high time they adopted more effective and productive material delivery and inspection methods which can enhance the productivity of the existing workforce. To deliver goods and services that are affordable, safe, and dependable, transportation infrastructure must keep up with global technology breakthroughs. If the material delivery process can be automated from inception to completion, the precision, reliability, and efficiency of all involved stakeholders can be enhanced. A computerized system such as e-Ticketing would make the transmission and compilation of this information more precise and efficient from a technical standpoint. Electronic ticketing and inspection technologies will significantly reduce the inefficiencies of the paper ticketing process which are discussed in the paper. Consequently, the productivity of inspectors and engineers will increase to a greater degree. The inspectors and administrative staff who were responsible for documentation, billing, and reconciliations are now able to assist with more important tasks, such as quality checks and inspection duties.

CHAPTER 8

DEVELOPING E-TICKETING EFFECTIVENESS INDEX FOR MATERIAL DELIVERY IN HIGHWAY CONSTRUCTION

Below is a published paper (Chapter 8).

8.1. Abstract

Electronic construction (e-Construction) is gaining popularity in the highway construction industry due to manpower shortages and resource limitations. Adoption of e-Construction technologies can improve the productivity and efficiency of resurfacing operations. Poor performance quality occasionally noticed in highway construction has a detrimental effect on service life and needs urgent attention. Despite the fact that e-Construction technologies, such as e-Ticketing, have helped enhance quality and performance in various other industries, the construction sector largely depends on and inclines toward old and traditional paper-based methods. To increase the use of digital material delivery in highway and bridge construction, stakeholders must have access to complete data and decision-supporting tools. The present study analyzes the critical effectiveness indicators (CEIs) of e-Ticketing technology and presents a fuzzy index-based method for evaluating the adoption priorities. An extensive review of the current literature was performed followed by a survey of qualified highway construction professionals in the United States. The findings reveal that the ticketing process, organizational, and technological factors have relatively equivalent impacts on the effectiveness model. The study's findings will assist practitioners with an assessment tool to gain insights relating to priority levels in implementing the e-Ticketing technology. The e-Ticketing Effectiveness Index (EEI) model can provide the state Department of Transportation (DOTs) and general contractors with a decision-making assessment tool which will facilitate in widespread adoption of e-Ticketing technology.

KEYWORDS: e-Construction, e-Ticketing, material delivery, highway, productivity.

8.2. Introduction

Over the past two decades, transportation authorities have experienced low productivity rates and quality issues. The lack of trained inspectors and engineers and dependence on traditional management techniques which are paper based have added to this slow progress (Nipa and Kermanshachi 2022). According to NCHRP Synthesis 450, DOTs are managing bigger highway networks with fewer inspectors than they had a decade ago. From 2000 to 2010, state-owned highway lane miles rose by an average of 4.10 per cent for the 40 [DOTs] that answered to the study, while the total number of full-time employees declined by approximately 9.6 per cent (Taylor and Maloney 2013). Public sector employment is being discouraged by lower pay, budget constraints, and a booming private sector. Due to retirement, qualified and experienced individuals are departing state agencies and are being replaced by inexperienced personnel who undertake various responsibilities early in their careers. Several DOTs do not even fill the posts. The cumulative effects of these obstacles are damaging to DOT employees, especially those employed in the daily operations and construction divisions. Inspectors have either left the state DOTs to work for private companies or are retiring, according to recent studies conducted for the Indiana Department of Transportation by Cai et al. (2020) and by Xu et al. (2019). According to Rush (2021), the Kentucky Department of Transportation has experienced a lack of inspectors in a similar manner.

Each year, DOTs are responsible for collecting an enormous amount of paper tickets for the delivery of asphalt, concrete and other construction material supplies. These tickets are used to track the delivery of these materials. Paper was traditionally used throughout the process of collecting, distributing, storing, and archiving load delivery tickets for highway projects. The collection of material tickets which are paper based, however, is an inefficient technique that puts construction inspectors in danger of several threats to their health and safety

(ALDOT Annual Report 2019). Inspection tasks include performing work very close to moving or backing machinery, collecting tickets by boarding the side of trucks and strolling in traffic intense areas putting inspectors in a position where they face a significant danger (Dadi et al. 2020; Subramanya et al., 2022d). Human resources must be allocated to gather, arrange, store, and maintain load delivery tickets for the purposes of project management and documentation when using a paper-based ticketing system. Load tickets are taken back to the project office and totaled and entered into an Excel spreadsheet for the purposes of reporting, reconciliation and payment in a paper-based ticketing system. (Subramanya and Kermanshchi 2021). Paper load tickets run the risk of being misplaced or lost while being transmitted because of human mistakes and negligence. In certain instances, it might be challenging to see the information printed on the paper ticket because of bad printing quality (Nipa et al. 2019; Subramanya et al., 2022e).

This was the ideal beginning point for DOTs, general contractors, associated transportation organizations, and authorities to investigate innovative technologies in more depth to compensate for workforce cutbacks. Using contemporary electronic construction tools and semi-automated technologies can assist DOTs in maintaining reliable and safe roadways to encounter growing demands and related issues (FHWA 2017; FHWA 2018). Transportation agencies have been changing and combining existing paper-based ticketing systems with digital and electronic workflows which are known as e-Ticketing technology. It has the capability to improve worker safety by removing the need for employees to evade project vehicles to get paper tickets from truck drivers, boost project efficiency resulting in faster payments to contractors and material vendors, and increase worker productivity by concentrating on many other project-related duties (Schultz 2020; Nipa and Kermanshachi 2019). This technology is also advantageous in the management of assets, as information on material placed at certain sites can be taken into account when analyzing factors impacting pavement performance (Embacher 2020; Sturgill et al., 2019). Electronic ticketing may be seen as part of an e-Construction system, which is an electronic alternative to a conventional construction system in which records are recorded and stored on paper throughout the life of a project.

Electronic Ticketing (e-Ticketing) is a unique solution that has been pilot tested by state DOTs since 2015 (Sadasivam and Sturgill, 2021; Tripathi et al., 2022; FHWA, 2020; FHWA, 2021; Robertson et al., 2022), but only a small number of states have used the technology (Subramanya et al., 2022). Multiple studies have been undertaken to study its numerous benefits, but no decision-making resource is developed to illustrate the effectiveness of installing an e-Ticketing platform by state DOTs and general contractors. Hence, the purpose of this study is to establish a model for an e-Ticketing effectiveness indicator in the highway construction industry. To accomplish this, the authors have condensed the technique into two specific objectives: (1) determine the importance severity index of e-Ticketing adoption indicators; and (2) design a method for assessing the effectiveness of e-Ticketing in highway construction. To discover the underlying elements of e-Ticketing effectiveness, a comprehensive literature study was conducted. The validity and effectiveness of the indicators were then evaluated by sending a questionnaire to industry experts in the field of highway construction. Lastly, a strategy for building an e-Ticketing effectiveness index model is outlined and an evaluation and assessment tool is created.

8.3. Literature Review

A study of the relevant literature was carried out in order to gain an understanding of the existing e-Ticketing technology indicators that might be utilized to automate the delivery of asphalt and concrete during highway construction. The study has gathered information on the issues and challenges that are associated with the process of delivering materials for highway construction. The review of the relevant literature is divided into four parts, which are as follows.

8.3.1. Digitization

In the growth of modern infrastructure projects, digitization has encountered severe difficulties. The majority of industries, including industrial production, entertainment, and services, are trying to find solutions to quality, safety, and production challenges, resulting in significant performance and overall improvements (Subramanya and Kermanshachi 2022; Nipa et al., 2022). However, the transportation industry has been slow to embrace the changes (Elghaish et al., 2020; Safapour et al., 2022). e-Ticketing permits the digital transmission of material tickets, such as asphalt and concrete, which account for over half of construction costs. Since the 1990s, as the construction sector has struggled to implement technology, academics have investigated mobile technology solutions that decrease the administrative labor necessary for construction field documentation (Bossink 2004). During EDC-3 (2015–2016), the FHWA launched e-Construction as an innovation in recognition of the fact that the use of paperwork to manage highway projects made logistics, scheduling, and communication increasingly difficult and unworkable. For this reason, the agency decided to go with electronic documentation since it's less time-consuming and costly than paper-based documentation. The collecting, evaluation, approval, and dissemination of construction contract papers in a paperless environment was characterized widely by FHWA for EDC-3 as "e-construction" by the agency (FHWA 2018). Electronic signatures, secure file sharing, version control, web-hosted data archiving, mobile devices, retrieval systems and RFID tags for resource tracking were all part of the attempt to adopt readily available and well-established technologies.

8.3.2. Challenges in Highway Construction

It is believed that highway construction demands long-distance and dispersed logistical solutions together with strict deadlines, making it difficult to manage (Nipa et al., 2022). With each passing day of delay, the cost of raw materials, labour, and utilities would increase significantly. When dealing with a multi-tiered third-party system, traditional management techniques typically fall short of expectations. As was historically the case with project budgets, significant attention must be paid to project schedules. For state DOTs and general contractors, producing, recording, classifying, and documenting paper tickets is a costly and time-consuming procedure. (Sadasivam and Sturgill 2021). During a project, contractors and owner's representatives often need bills of materials, test reports, inspection records, and many other information-based records (Subramanya and Kermanshachi 2022). Since the majority of highway construction work is conducted on-site, documents must be transferred to computers, necessitating data re-entry, or retained in a burdensome, inaccessible paper format. Physically collecting delivery truckload tickets exposes field inspectors to many safety dangers, including going across traffic and boarding vehicles to obtain paper tickets (Patel et al., 2019; Embacher 2020). The paper-based documentation is unintelligible since the majority of asphalt plant owners continue to use dot matrix printers with carbon copies (Subramanya et al., 2022).

Few DOTs still require their administrative staff to manually scan each paper ticket into document management software, a difficult and time-consuming repeating operation (Sturgill et al., 2019; Subramanya and Kermanshachi 2022). A material ticket is required for material delivery to a state DOT project. Typically, material records are produced, sent, approved, recorded, and maintained starting with the source (material vendor) and continuing through the delivery and documentation. These records are required to maintain track of acquired materials and to pay the contractor, material suppliers, and third-party transport/trucking agencies. These records are also used to complete a project, forming part of the final construction record for the project. Existing DOT processes rely heavily on paper-based documents and tickets. In projects involving several partners, modifications and change orders sometimes result in cumbersome processes. Due to the manual nature of the system and the necessity for many levels of data inspection, compiling daily material records is a time-consuming task.

The transportation industry has a number of organizational difficulties, including a shortage of skilled staff, issues with project quality, documentation, budget overruns, safety-related incidents, and schedule delays (Kermanshachi et al., 2017; Newcomer et al., 2018). According to Vidalis and Najafi (2002), the majority of construction projects encounter cost and schedule overruns, which may lead to budget overruns and project delays. These overruns might be caused by weather-related damage, utility bills, material supply delays, quality issues, and reconciliation of materials. The majority of transportation infrastructure projects have cost overruns, schedule delays, and quality issues, and inspectors and project engineers are few in rural and remote areas. 45,000 bridges and one out of every five miles of highways are in bad condition, according to a White House statement (The Bipartisan Infrastructure Deal, The White House 2022). Before the US infrastructure to catch up to that of China and Japan, the American Society of Civil Engineers (ASCE) estimates that a $2.6 trillion investment gap must be addressed (Siripurapu, 2021). The United States Department of Transportation (USDOT) has allocated $53 billion for fiscal year 2022 to upgrade roads, while the USDOT and the Federal Highway Administration have announced $27 billion in funding. The $1.2 trillion infrastructure package proposed by President Biden would fund surface transportation initiatives for an extra five years. It is great to see that new technologies are being included into this historic infrastructure initiative. The infrastructure law invests $100 million over five years in order to expedite the use of construction technologies such as digital twins, e-Ticketing, as-builts, and many more.

8.3.3. Electronic Ticketing in Highway Construction

Typically kept on a smartphone or computer, an electronic ticket is a document or a barcode that is subsequently used as proof of entrance or confirmation of a reservation. It may replace the antiquated practice of issuing paper tickets, which prevents and hinders users from updating and monitoring events. The utilization and advantages of this platform are well suited to be implemented in the highway construction industry for monitoring the kind and amount of mix materials, as well as truck departure and arrival times (Subramanya and Kermanshachi 2022). Various state DOTs have tried the notion of electronic distribution of material delivery tickets since 2015. e-Ticketing is the digital transmission of material load tickets in real-time using internet-connected smart devices. This offers enterprises the opportunity to go paperless and reduce paper handling on building sites. Eliminating paper tickets improves safety and productivity, lowers environmental waste, prevents the loss or damage of tickets, and improves project management (Brinckerhoff 2017). A recent study by Tripathi et al. indicates that it takes inspectors 57 minutes to physically collect and verify 19 paper tickets; using e-Ticketing, the same information may be obtained in 8 minutes. e-Ticketing data is broadcast in real-time to a cloud-based digital database, allowing mobile devices to access it as needed. It establishes a single source of data input that can be immediately shared with the document management systems of state transportation departments (DOT) for information retrieval, mining data insights and one-click payments for materials delivery (Subramanya and Kermanshachi 2021). In the construction of highway infrastructures, the use of raw materials will account for approximately more than fifty per cent of the overall project budget; thus, proper monitoring and recording of these tickets are essential for the success of current and future projects. Prior to the outbreak of the Covid-19 virus, this technology's implementation and pilot testing were minimal (FHWA 2021). The recent outbreak of the pandemic has impacted the day-to-day responsibilities performed by inspectors and engineers. Companies have devised clever ways for workers to work from home or in remote locations. Similarly, the highway construction sector has prioritized the use of e-Ticketing technology. The introduction of Covid-19 resulted in the partial deployment of the e-Ticketing platform in which inspectors would receive tickets as image files (Pdf/JPEG). Even if image-based files are adequate for electronic transmission and human comprehension, the original paper ticket must be provided to the project by the contractor or supplier in most of scenarios. Since the picture files include unstructured and non-machine-readable data, the information must be manually extracted and entered into the DOTs' construction management software.

8.4. Indicators for e-Ticketing Adoption

Multiple studies have emphasized the operational problems and factors related to the deployment of technology which semi-automates or simplifies the daily operations in the construction sector. Ozorhon and Oral (2017) state that the impact of operational constraints should be mitigated through technology implementation and innovation. Considered determinants (or indicators/factors) of the propensity to embrace technology or a set of technologies are drivers and obstacles (Nnaji et al. 2019). A company's decision to employ this technology may be influenced by the presence or absence of certain indicators. As stated by Nikas et al. (2007), in order for new and cutting-edge construction technology to be widely accepted and employed, all stakeholders in the construction industry must have a strong connection. In order to accomplish effective technology integration, it is vital to consider not only technical but also organizational indicators in the process of reviewing (Nikas et al. 2007; Pan et al. 2018). Technology, organization, and operational difficulties have been shown to have the most impact on whether or not automation is used. (Yang et al. 2007; Nnaji et al. 2019). The current research categorizes the indicators as follows: (1) Ticketing process indicators; (2) technology indicators; and (3) organization indicators. Existing research which has suggested possible determinants and indicators of e-Ticketing Effectiveness Readiness (EER) are summarized in Table 8.1.

Table 0-1 Indicators of e-Ticketing technology readiness

Indicators	References														
	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**	**l**	**m**	**n**	**Count**
Technology adoption indicators (Level of Importance)															
Manually entering ticket details can be automated.	X	X		X		X	X		X	X		X	X	X	**10**
Documentation of billing and invoices can be automated	X	X				X		X	X			X		X	**7**
Increased morale and efficiency of inspectors		X		X	X		X	X	X	X					**7**
Inspectors/engineers can handle multiple projects		X	X			X			X			X		X	**6**
Site hazards can be prevented to a certain extent	X	X		X	X	X	X		X	X	X	X			**10**
All stakeholders can stay connected in real-time		X		X	X	X			X	X	X		X	X	**9**
Inspectors can collect, review, and document more tickets	X		X					X	X				X	X	**6**
Paper ticketing inefficiencies indicators (Level of occurrence)															
Errors in reconciliation	X		X	X		X			X	X		X	X	X	**9**
Errors in cumulative tonnage	X	X		X	X	X	X						X		**7**
Lost paper tickets		X				X		X						X	**4**
Inaccurate ETA of material delivery trucks	X	X		X		X				X		X			**6**
Excessive wastage of material		X						X			X		X		**4**
One ticket being accounted for multiple times		X							X						**2**
Wrong ticket sent with the load		X						X	X					X	**4**
Organizational indicators (Level of occurrence)															
Workforce shortage of engineers and inspectors	X	X	X	X	X	X	X		X	X	X	X	X	X	**13**
Schedule delay due to operational challenges		X			X		X	X		X	X		X	X	**8**
Cost overruns due to quality issues				X		X	X		X	X	X	X		X	**8**

Note: a = Robertson et al., 2022; b = Subramanya et al., 2022; c = Tripathi et al., 2022; d = Patel et al., 2019; e = Sadasivam et al., 2021; f = Sturgill et al., 2019; g = Nipa et al., 2019; h = Bajwa 2018; i = Subramanya and Kermanshachi 2022; j = Newcomer et al., 2018; k = Mohamed et al., 2022; l = Dadi et al., 2020; m = Embacher 2021; n = Subramanya et al., 2022.

8.5. Research Methodology

This research included a multiphase strategy that included a structured literature review and the distribution of a survey questionnaire. Figure 8.1 graphically depicts the research methodology. The authors searched numerous online databases, including ASCE Library, Google Scholar, Web of Science, and Scopus, to uncover relevant literature on technology usage, e-Ticketing implementation, and material delivery process challenges in highway construction. Table 8.1 consists of seventeen indications that may be utilized to predict an agency's readiness to implement an e-Ticketing system. These indicators are categorized as technology adoption, organizational, and ticketing process indicators. Data and information obtained from the review of the literature was also important in drafting the survey questions since it provided insight into readiness indicators and reasoning.

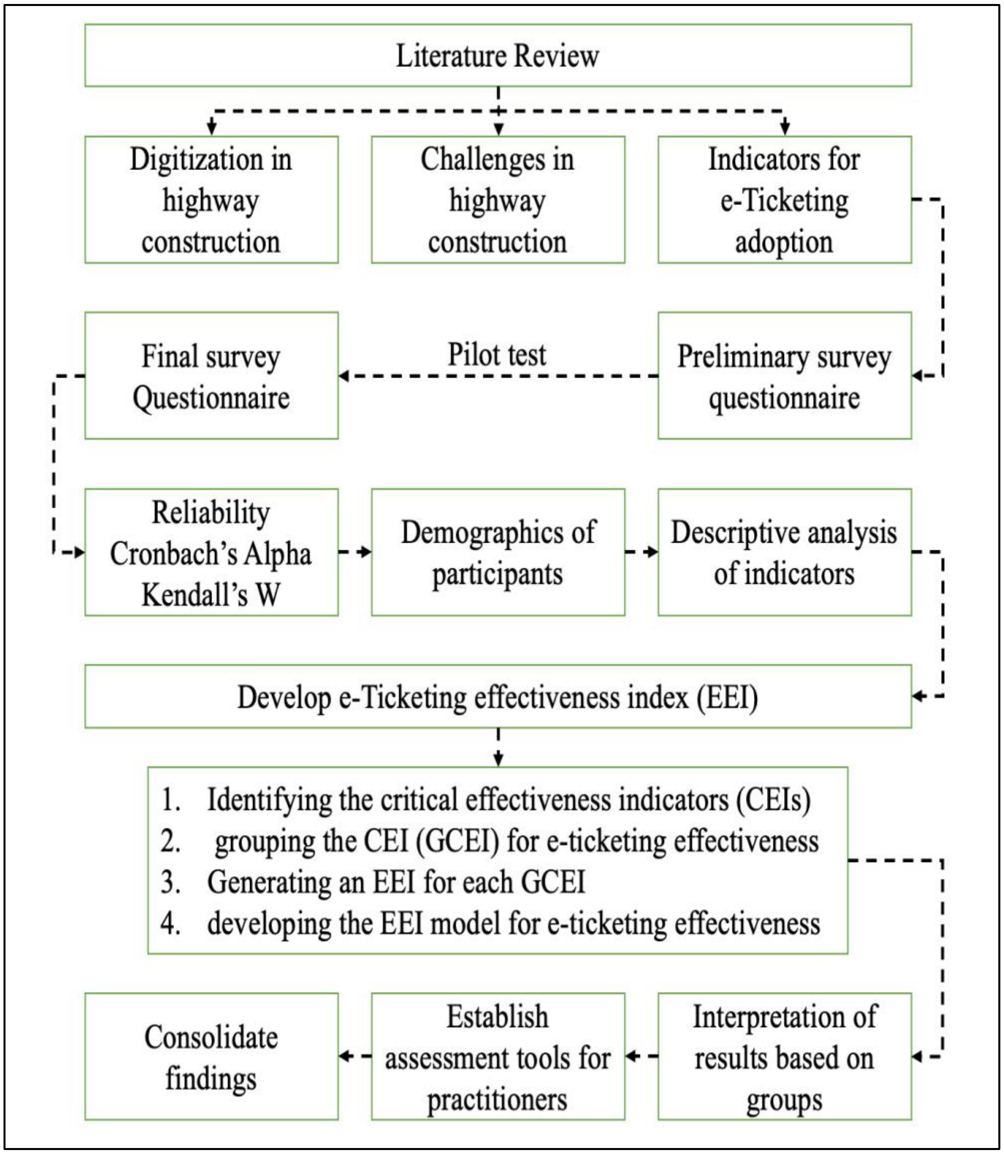

Figure 0-1 Research Methodology

8.5.1. Survey Development and Distribution

The survey questions were formulated into 3 sections. The purpose of the first section of the survey is to gather basic demographic data about the participants. Section two gathered data about the e-Ticketing technology benefits and operational challenges in highway construction. The survey employed a seven-point Likert scale, with 1 denoting the least significance and 7 being the highest. The final segment assessed the participant's perceptions of the final list of indicators relating to e-

Ticketing adoption. Purposive sampling was used to find experts in the highway construction business with expertise in quality management and technology/automation management in order to guarantee that the results provide sufficient information about this industry (Pan et al. 2018). Prior to distributing the survey, the authors ran a preliminary pilot test to check that the indicators are accurate and that the questionnaire is straightforward to interpret. Using publicly accessible lists, as purposive sampling, the survey yielded a total of 53 completed responses. To improve the validity and reliability of the findings, the study has eliminated individuals who completed all questions in less than 200 seconds. 34 individuals fulfilled these standards and passed the quality inspections. Studies involving surveys from the construction industry show fewer replies compared to other industries due to the excessively hectic schedules of many construction professionals (Ameyaw et al. 2017).

8.5.2. Demographics of participants

The survey questionnaire contained information relating to the demographics of the participants. As evident from Table 8.2, most respondents (41.2 percent) in the dataset had more than 25 years of experience, while respondents with 2-5 years of experience represented 2.9% of the entire dataset. It is evident that the participants had extensive knowledge of the construction industry and that they could be relied upon to provide reliable feedback pertinent to the current study. 73.5 percent of the participants in the dataset were employed by the State Department of Transportation. In addition, 11.8 percent of the participants were from general contracting firms. Interestingly, there were a significant number of participants (5.8 percent) who represented material suppliers, technology providers/vendors, FHWA employees, or consultants.

Table 0-2 Experience years of participants

Experience years in construction industry		
	Frequency	***Percentage***
Less than 2 years	2	5.9
2 - 5 years	1	2.9
5 – 10 years	5	14.7
10 - 15 years	6	17.6
15 - 20 years	3	8.8
20 - 25 years	3	8.8
Above 25 years	14	41.2
Total	34	100.0

8.5.3. Frequency and Percentage of Indicators

This section displays the frequency and percentage distributions of the responses for all the indicators of e-Ticketing effectiveness, which are then utilized in the final section of this data analysis for the development of an e-Ticketing effectiveness index. The majority of respondents (44.1 percent) agreed that manually entering ticket details requires a significant amount of effort and should be automated, whereas a much smaller percentage of respondents disagreed with this statement (Figure 8.2). The majority of respondents (44.1 percent) agreed that billing and invoice documentation must be automated, while a much smaller proportion of respondents disagreed. Most participants (41.2 percent) strongly agreed that there is a threat to inspectors' safety while collecting load paper tickets in transportation infrastructure, whereas no participants expressed disagreement with this statement.

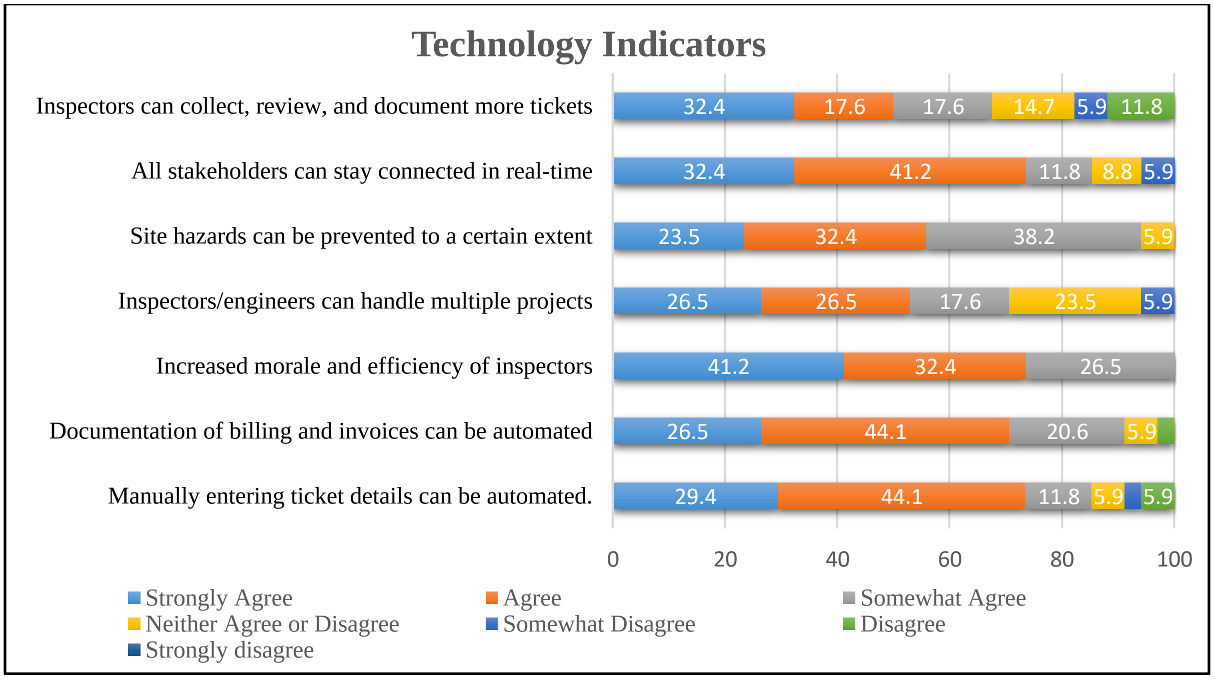

Figure 0-2 Descriptive data related to technology indicators

According to Figure 8.3, the majority of respondents (41.2 percent) stated that cost overruns occur occasionally in the construction industry. However, only 5.9 percent of those polled said it happens frequently. According to their experience, most respondents (35.3 percent) stated that there are occasionally schedule delays in the construction industry. However, only 29 percent of participants stated that it occurs frequently. According to their experience, many respondents (32.4 percent) stated that there is frequently a workforce shortage of engineers and inspectors in the construction industry. However, only 5.9 percent of participants stated that it occurs infrequently.

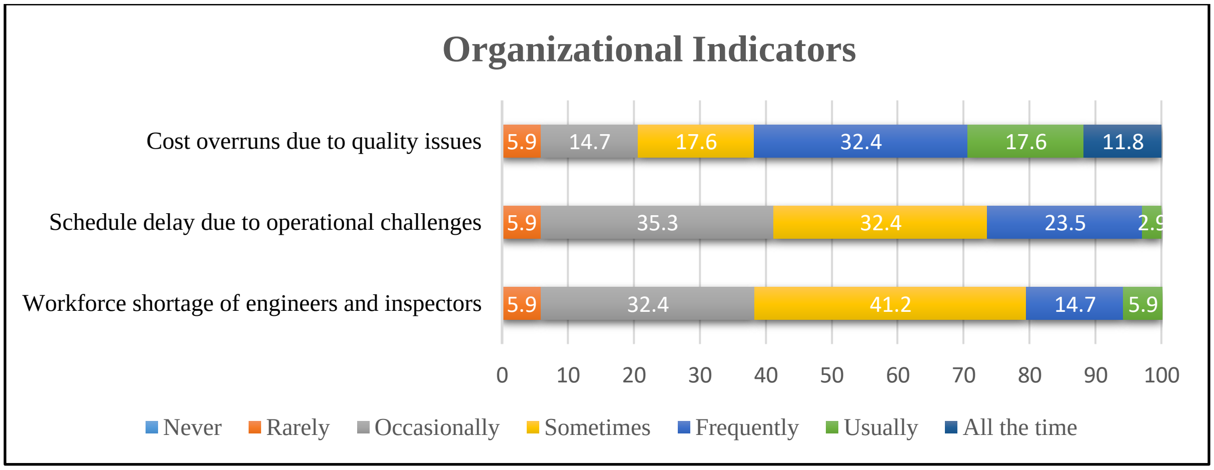

Figure 0-3 Descriptive data related to organizational indicators

Most respondents indicated that cumulative tonnage errors do happen occasionally in the construction industry. Only 2.9% of participants, though, said that this was a frequent occurrence (Figure 8.4). 8.8% of respondents said that reconciliation errors happen frequently in the construction industry, but the majority said they happen occasionally. Many respondents' experiences in the construction industry indicate that it is uncommon for a single ticket to be accounted for more than once. Only 5.9% of participants, in contrast, said that this happens frequently. 42 percent of the respondents, who made up the majority, agreed that in their experience, wrong tickets are rarely sent with loads. Only 2% of the participants, however, highlighted the fact that it occurs frequently. Only 2.9 percent of participants said that paper tickets are lost frequently, despite the fact that the majority of participants (41.2 percent) said that it happens occasionally.

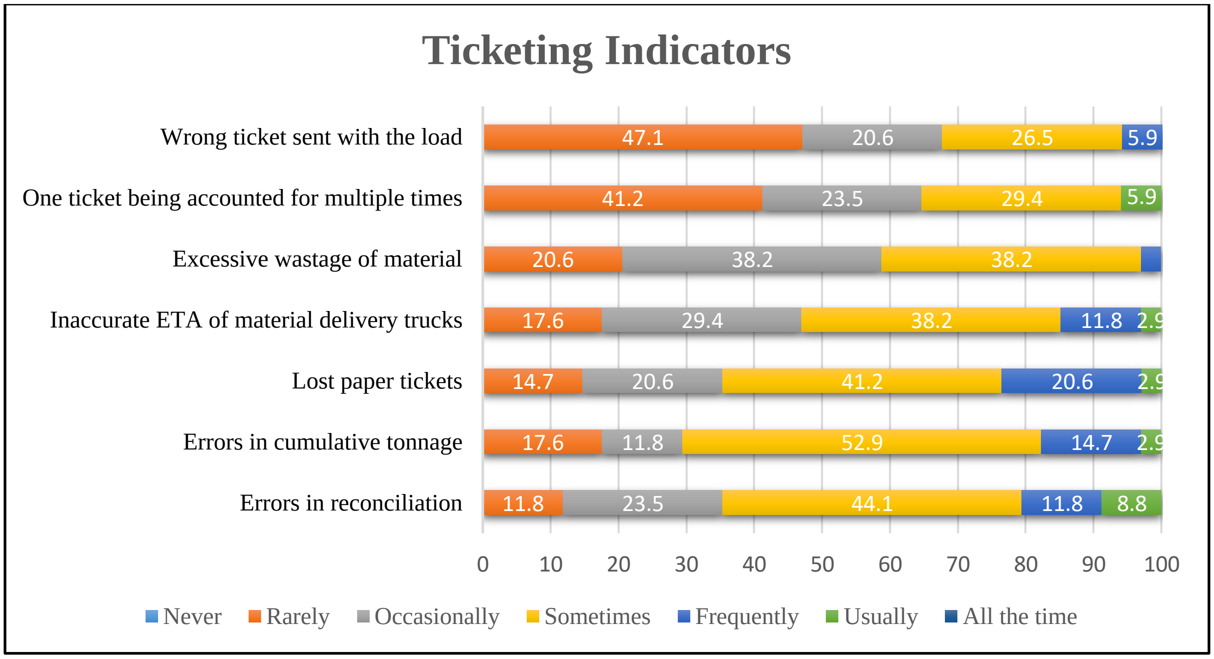

Figure 0-4 Descriptive data related to ticketing process indicators

8.5.4. Reliability Analysis

Prior to running the other statistical analyses, the data's reliability was determined. This study employed Cronbach's Alpha to determine the level of concordance between the e-Ticketing adoption readiness indicators. Cronbach's is an efficient instrument for the measurement of the study's reliability and assessing the data's quality prior to analysis. The reliability for each construct of e-Ticketing adoption readiness employed in this study was examined (Table 8.3), and all values were found to be greater than 0.70, thereby enhancing the reliability of the survey instrument employed. In the opinion of Lam and Javed (2015), a coefficient value of at least 0.70 is considered appropriate. Using the FSE-based model, this phase ensured the validity of the data scales used in this research.

Table 0-3 Reliability Analysis using Cronbach's Alpha

Indicators Group	Cronbach's Alpha	No. of Items
Ticketing Process Indicators	0.791	7
Organizational Indicators	0.751	3

Technology Indicators	0.853	7

Note: Threshold of 0.7 was used to check reliability

8.5.5. Kendall's W

The Kendall's W test is used to verify if all of the participants in the research are in an overall agreement, which is a crucial step in determining response consistency (Chan et al. 2009). This variable's value falls between 0 and 1, with a strong agreement inferred when the value is close to or greater than 1. We found that Kendall's W (0.355) and the chi-square (193.182) had a significance level of 0.000, using a 16-degree-of-freedom sample size for the survey (Table 8.4). At a significance level of 0.05, this finding reveals a high degree of agreement and consistency across survey participants, hence validating the survey responses' validity and authenticity.

Table 0-4 Kendall's Test for Concordance

Test Statistics	
Kendall's W[a]	.355
Chi-Square	193.182
df	16
Asymptotic Significance	.000

a. Kendall's Coefficient of Concordance

8.5.6. Ranking Analysis Methods

This study used Importance Severity Index and FSE to propose the e-Ticketing Effectiveness model for e-Ticketing in construction. Firstly, Importance Severity Index was obtained to evaluate the relative importance of e-Ticketing effectiveness indicators based on the collected data. It should be noted that the ratings on the scale merely reflect the order of significance of the criteria, not how much more essential one rating is than the other. Using parametric statistics (means, standard deviations, and so on) to classify this information would generate meaningless results, hence non-parametric approaches should be used (Chen, 2010). Current study employed importance severity index analysis to classify and order the e-Ticketing adoption readiness as per their Severity index analysis was selected in this study to rank the criteria according to their comparative importance. Equation 1 is employed to determine the importance severity index (Chen, 2010):

$$\text{Importance Severity Index (ISI)} = \left(\sum_{i=1}^{7} w_i \times \frac{f_i}{n} \times 100\right) \div (a \times 100) \quad (1)$$

In the above equation, a Likert scale rating of "1" and "7" is used for “i” and “wi”; “i” is the point given to each criterion by the responder; wi is the weight for each point. For all respondents, n is the total number of replies; fi is the frequency of point “i”. In this investigation, "a" carries the most weight; its value was calculated as 7 in this study. Five important levels are transformed from ISI values: High (0.8 ≤ ISI ≤ 1), High–Medium (0.6 ≤ ISI ≤ 0.8), Medium (0.4 ≤ ISI ≤ 0.6), Medium–Low (0.2 ≤ ISI ≤ 0.4), and Low (0 ≤ ISI ≤ 0.2). With SPSS v.26, severity index values were derived using Equation 1 based on the survey findings. Based on the magnitude of the importance severity index one indicator was highlighted to have “High-Medium” importance levels in evaluating e-Ticketing effectiveness in construction with an ISI value of 0.68. The first three indicators according to their rank are related to organizational which are; workforce shortage of engineers and inspectors, schedule delays and cost overruns, next 7 indicators in ranking are related to technology process which are; errors in reconciliation, errors in cumulative tonnage, lost paper tickets, inaccurate ETA of material delivery trucks, excessive wastage of material, one ticket being accounted for multiple times, wrong ticket sent with the load, and last 7 indicators in the ranking table are related to technology indicators which are; manually entering ticket details require a significant level of effort and needs to be automated, documentation of billing and invoices needs to be automated, there is a threat to the safety of inspectors while collecting load paper tickets in transportation infrastructure, project engineers/inspectors/managers can handle multiple projects smoothly with the e-Ticketing systems, site hazards can be prevented to a certain extent in road/bridge construction with the use of e-Ticketing systems, e-Ticketing will help inspectors, engineers, operators, material vendors, contractors and owners to stay connected, with e-Ticketing technology, inspectors and engineers can collect, review, and document significantly more tickets. After ranking the indicator based on ISI, the second step was to run Fuzzy Synthetic Evaluation. The FSE model procedure is given as follows:1. Develop and establish set of criteria = {i1, i2, i3, i4 …., in}, where n is the number of criteria.

2. Develop labels for the set of grade alternatives as L = {L1, L2, L3, L4 …., Ln} and use the 7-point Likert scale.

3. For each e-Ticketing adoption readiness indicator in the survey, set the weighting vector (Wi) as follows:

$$W_i = \frac{M_i}{\sum_{i=1}^{7} M_i} \; 0 \leq W_i \leq 1, \sum W_i = 1 \quad (2)$$

Where Wi is the weighing vector; M_i = MS of a particular indicator; and $\sum W_i$ = summation of the mean ratings. There are three components to this equation: a weighting vector (Wi), the MS of a specific indicator (M_i), and the summation of the mean ratings ($\sum W_i$).

4. Indicator-specific fuzzy evaluation matrices (Ri) should be constructed.

$$R_i = (r_{ij})_{m \times n}$$

where rij equals the degree to which Lj meets criterion ij.

5. Using the following formula, determine the final FSE results by evaluating Wi and Ri.

$$D = W_i \circ R_i \quad (3)$$

Where D = final FSE evaluation matrix; and ° = fuzzy composition operator.

6. The FSE evaluation matrix and the e-Ticketing Effectiveness Index (EEI) model should be normalized as follows:

$$\text{EEI} = \sum_{i=1}^{7} D \times L \quad (4)$$

8.6. Results and Analysis

Multiple steps comprise the data analysis: (1) identifying the critical effectiveness indicators (CEIs); (2) grouping the CEI (GCEI) for e-Ticketing effectiveness; (3) generating an EEI for each GCEI for e-Ticketing effectiveness; (4) developing the EEI model for e-Ticketing effectiveness; (5) and developing an e-Ticketing effectiveness assessment tool.

8.6.1. Selection of CEIs for Predicting e-Ticketing Effectiveness

On a seven-point Likert scale, participants were asked to rate their agreement with the statements or occurrences of the 17 e-Ticketing adoption readiness indicators. The analysis of the Mean Score, standard deviation, and ranking of the indicators are presented in Table 8.5. The mean item score ranged from 3.04 (Incorrect ticket sent with the load) to 6.04 (There is a threat to inspectors' safety while collecting load paper tickets in transportation infrastructure), indicating that all predictors identified in this study are crucial for determining the effectiveness of e-Ticketing. To identify the CEIs, the importance severity index was computed, and each indicator was assigned the appropriate weighting. Table 4 reveals that the first eleven indicators are considered the CEIs when predicting the effectiveness of e-Ticketing. CEI values greater than 0.50 are classified into three fundamental success predictor groups, namely ticketing process, organizational, and technology indicators, which were intended to facilitate the FSE (Table 8.5). The uniformity of the survey respondents was validated using Kendall's W, which determined the group's overall agreement with the Mean Score. The Mean Score and Importance Severity Index determined the indicators' significance.

8.6.2. Grouping and Weighing the CEIs and GCEIs for e-Ticketing Effectiveness

Based on Table 5, the three CEI groups include indicators for the ticketing process (Group 1), organizational (Group 2), and technology (Group 3). The indicator selection was based on the Importance Severity Index (Table 5). Using Equation (2), the weights of the CEIs and GCEIs were calculated to determine the member composition. For Ticketing Process Indicators ($\mathrm{W}_{\mathrm{CEI1}_1}$), organizational indicators ($\mathrm{W}_{\mathrm{CEI2}_1}$), and technology indicators ($\mathrm{W}_{\mathrm{CEI3}_1}$) the following sample expressions were used to measure weights for each item:

$$\mathrm{W}_{\mathrm{CEI1}_1} = \frac{Mean\ Score\ of\ CEI}{Sum\ of\ Means\ of\ Group\ 1} = \frac{3.74}{24.06} = 0.155 \approx 0.16 \qquad (5)$$

8.6.3. Determination of Membership Functions from Level 2 (CEIs) to Level 1 (GCEIs)

The degree to which an element is considered to be a part of a fuzzy set, which is sometimes referred to as a membership function (MF), typically ranges from 0 to 1 in most cases. Therefore, the MFs for CEIs are computed first, followed by the MFs for GCEIs. This is because the MFs are derived from Level 2 (CEIs) to Level 1 (GCEIs) (Osei-Kyei and Chan, 2017). The participant evaluations that were given in response were then applied to the MF in the form of selecting alternative possible grade levels. The following sample expression illustrates the calculations performed for MF for each CEI across all groups (one group shown below). The MF of all the indicators is shown in Table 8.7. The equations below represent the computations and calculations involved. The other two GCEIs were evaluated using a process that was very similar to the first one, and the results are presented in Table 3. Following the completion of the MF calculation for Level 1, the EEI for each GCEI is determined (Table 8.6). For example, the EEI for Group 1 (TPI) can be calculated as follows:

$$\text{MFCEI1}_1 = \sum_{i=1}^{7} \frac{\textit{Proportion of each ranking}}{\textit{Value of each rank}} = \frac{0.00}{1} + \frac{0.18}{2} + \frac{0.12}{3} + \frac{0.53}{4} + \frac{0.15}{5} + \frac{0.03}{6} + \frac{0.00}{7}$$

$$\text{EEI}_{\text{GCEI1}} = \left(\text{r}_{ij}\right)_{mxn} = |0.00 \quad 0.23 \quad 0.24 \quad 0.39 \quad 0.10 \quad 0.03 \quad 0.00| \times |1 \quad 2 \quad 3 \quad 4 \quad 5 \quad 6 \quad 7| \qquad (6)$$

Table 0-5 Importance severity index

	e-Ticketing Effectiveness Indicators	Percentages							Mean	Importance Severity Index (ISI)	Importance	Rank
		1	2	3	4	5	6	7				
Technology Indicators (Level of Agreeability/Importance)												
1	Manually entering ticket details can be automated.	10	15	4	2	1	2	0	2.26	0.32	Medium-Low	13
2	Documentation of billing and invoices can be automated	9	15	7	2	0	1	0	2.15	0.31	Medium-Low	15
3	Increased morale and efficiency of inspectors	14	11	9	0	0	0	0	1.85	0.26	Medium-Low	17
4	Inspectors/engineers can handle multiple projects	9	9	6	8	2	0	0	2.56	0.37	Medium-Low	12
5	Site hazards can be prevented to a certain extent	8	11	13	2	0	0	0	2.26	0.32	Medium-Low	14
6	All stakeholders can stay connected in real-time	11	14	4	3	2	0	0	2.15	0.31	Medium-Low	16
7	Inspectors can collect, review, and document more tickets	11	6	6	5	2	4	0	2.79	0.40	Medium-Low	11
Ticketing Process Indicators (Level of Occurrence)												
8	Errors in reconciliation	0	4	8	15	4	3	0	3.74	0.55	Medium	4
9	Errors in cumulative tonnage	0	6	4	18	5	1	0	3.82	0.53	Medium	6
10	Lost paper tickets	0	5	7	14	7	1	0	3.06	0.54	Medium	5
11	Inaccurate ETA of material delivery trucks	0	6	10	13	4	1	0	2.91	0.50	Medium	7
12	Excessive wastage of material	0	7	13	13	1	0	0	3.76	0.46	Medium	8
13	One ticket being accounted for multiple times	0	14	8	10	0	2	0	3.53	0.44	Medium	9
14	Wrong ticket sent with the load	0	16	7	9	2	0	0	3.24	0.42	Medium	10
Organizational Indicators (Level of Occurrence)												
15	Workforce shortage of engineers and inspectors	0	2	5	6	11	6	4	3.82	0.68	High-Medium	1
16	Schedule delay due to operational challenges	0	2	12	11	8	1	0	3.82	0.55	Medium	2
17	Cost overruns due to quality issues	0	2	11	14	5	2	0	4.76	0.55	Medium	3

Table 0-6 Ranking of the CEIs for e-Ticketing Effectiveness

	Mean Score for CEI	Weights for Each CEI	Total Mean Score for each GCEI	Weights for Each GCEI
Ticketing Process Indicators				
Errors in reconciliation	3.74	0.16	24.06	0.46
Errors in cumulative tonnage	3.82	0.16		
Lost paper tickets	3.06	0.13		
Inaccurate ETA of material delivery trucks	2.91	0.12		
Excessive wastage of material	3.76	0.16		
One ticket being accounted for multiple times	3.53	0.15		
Wrong ticket sent with the load	3.24	0.13		
Organizational Indicators				
Workforce shortage of engineers and inspectors	3.82	0.31	12.40	0.24
Schedule delay due to operational challenges	3.82	0.31		
Cost overruns due to quality issues	4.76	0.38		
Technology Indicators				
Manually entering ticket details can be automated.	1.85	0.12	16.02	0.31
Documentation of billing and invoices can be automated	2.15	0.13		
Increased morale and efficiency of inspectors	2.15	0.13		
Inspectors/engineers can handle multiple projects	2.26	0.14		
Site hazards can be prevented to a certain extent	2.26	0.14		
All stakeholders can stay connected in real-time	2.56	0.16		
Inspectors can collect, review, and document more tickets	2.79	0.17		
Total Mean Score for All GCEIs			**52.48**	

Table 0-7 Weighting of CEIs and GCEIs for e-Ticketing Effectiveness

		Membership functions at level 2 (CEI)							Weights for Each GCEI at Level 1						
	Weights	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Ticketing Process Indicators															
Errors in reconciliation	0.16	0.00	0.18	0.12	0.53	0.15	0.03	0.00	0.00	0.23	0.24	0.39	0.10	0.03	0.00
Errors in cumulative tonnage	0.16	0.00	0.12	0.24	0.44	0.12	0.09	0.00							
Lost paper tickets	0.13	0.00	0.41	0.24	0.29	0.00	0.06	0.00							
Inaccurate ETA of material delivery trucks	0.12	0.00	0.47	0.21	0.27	0.06	0.00	0.00							
Excessive wastage of material	0.16	0.00	0.15	0.21	0.41	0.21	0.03	0.00							
One ticket being accounted for multiple times	0.15	0.00	0.18	0.29	0.38	0.12	0.03	0.00							
Wrong ticket sent with the load	0.13	0.00	0.21	0.38	0.38	0.03	0.00	0.00							
Organizational Indicators															
Workforce shortage of engineers and inspectors	0.31	0.00	0.06	0.15	0.18	0.32	0.18	0.12	0.00	0.05	0.25	0.27	0.18	0.06	0.02
Schedule delay due to operational challenges	0.31	0.00	0.06	0.35	0.32	0.24	0.03	0.00							
Cost overruns due to quality issues	0.38	0.00	0.06	0.32	0.41	0.15	0.06	0.00							
Technology Indicators															
Manually entering ticket details can be automated.	0.12	0.41	0.32	0.27	0.00	0.00	0.00	0.00	0.43	0.48	0.35	0.12	0.03	0.03	0.00
Documentation of billing and invoices can be automated	0.13	0.27	0.44	0.21	0.06	0.00	0.03	0.00							
Increased morale and efficiency of inspectors	0.13	0.32	0.41	0.12	0.09	0.06	0.00	0.00							
Inspectors/engineers can handle multiple projects	0.14	0.29	0.44	0.12	0.06	0.03	0.06	0.00							
Site hazards can be prevented to a certain extent	0.14	0.24	0.32	0.38	0.06	0.00	0.00	0.00							
All stakeholders can stay connected in real-time	0.16	0.27	0.27	0.18	0.24	0.06	0.00	0.00							
Inspectors can collect, review, and document more tickets	0.17	0.32	0.18	0.18	0.15	0.06	0.12	0.00							

8.6.4. Developing e-Ticketing Effectiveness Index

A composite EEI was developed through the utilization of a linear and additive model in order to make a prediction regarding the effectiveness of e-Ticketing in the construction industry. Research on technology benchmarking and the creation of an innovative solutions assessment index are both made possible with the help of the linear model. (Nnaji et al. 2020; Ogunrinde et al., 2021). In addition, previous studies have utilized additive or linear models to develop indexes (Lam and Javed 2015). The linear model is standardized to return a sum of 1 or unity in order to generate the composite index (Table 8.8). Expression of the EEI for construction ticketing processes:

$$\begin{aligned} \text{EEI} = &(0.346 \times \text{Ticket Processing Indicators}) \\ &+ (0.328 \times \text{Organizational Indicators}) \\ &+ (0.326 \times \text{Technology Indicators}) \qquad (7) \end{aligned}$$

Table 0-8 EEI and the coefficient for each group

Indicators	1	2	3	4	5	6	7	e-Ticketing Effectiveness Index	Co-efficient
Ticketing Process Indicators	0.00	0.23	0.24	0.39	0.10	0.03	0.00	3.47	0.346
Organizational Indicators	0.00	0.05	0.25	0.27	0.18	0.06	0.02	3.29	0.328
Technology Indicators	0.43	0.48	0.35	0.12	0.03	0.03	0.00	3.27	0.326
Total								**10.03**	**1.000**

8.7. Discussion

The EEI model will provide stakeholders in the highway construction industry with vital information that guides the automation of work processes. Using the proposed model, individuals involved in technology adoption can assess the readiness of organizations to adopt and implement e-Ticketing technology. Additionally, the model can be applied to the process of comparing multiple vendors in order to assist the organization in determining which option and features the vendors are providing at a given time are the most suitable option. The adoption of the suggested model as a decision support instrument can make it easier for businesses in the highway construction industry to adopt new technologies, thereby reducing the inherent quality problems that are associated with traditional methods.

8.7.1. Grouped Indicators

The results of the analysis yielded ticketing process indicators as the most important category of indicators when accessing the readiness to implement e-Ticketing technology. The co-efficient for the group is 0.346 and consists of 7 indicators and “errors in cumulative tonnage” was ranked the highest with a mean score of 3.82. The ticketing process indicators will play a major role in understanding the importance of e-Ticketing technology. The conventional method of paper ticketing is filled with inefficiencies, as seen by the responses of the participants based on occurrences. When the dump truck reaches its destination, an engineer records the truck number, the time it arrived, and the location of the pour. This information is frequently used for tallying the tickets at the end of the day and manually calculating cumulative tonnage to ensure that all the data is consistent. If the inspector is not there, someone else, often a foreman, takes the ticket and puts it to a clipboard for subsequent verification by the inspector which is not an efficient method. The majority of states continue to scan each paper ticket and store the physical copy for 'n' years in DOT-owned facilities. Some states manually insert ticket information into Excel files as opposed to scanning them, while others scan paper tickets into PDF format and dispose of the hard copy. Some material factories still utilize antiquated DOT matrix printers with carbon copies, which makes it impossible to read some data and causes billing and payment delays due to the loss of paper tickets. In several projects, the truck driver provides the foreman multiple copies of the ticket, which is a laborious process.

The second group is the organizational indicators is the organizational indicators which has a co-efficient value of 0.328. There are a total of three indicators in this group which are “workforce shortage of engineers and inspectors”, “schedule delays due to operational challenges” and “cost overruns due to quality issues”. Among the three indicators used in the study, cost overrun was ranked the highest with the mean score of 4.76 while workforce shortage and schedule delay have the same mean score of 3.82. The standard paper ticketing technique for processing materials for transportation projects is inefficient and negatively impacts project costs and duration. The three indicators are slightly inter-related with each other. The schedule delays in highway construction will often lead to cost overruns. These cost overruns in highway construction are usually faced and tackled by the general contractors and not by the state DOTs. The shortage of workforce will eventually lead to quality issues and in-turn cause cost overruns and schedule delays in highway projects. It is evident from the literature that the cost overruns result from material shortage, labor shortage, late delivery of materials and equipment, lack of competent staff, and low labor productivity.

The third group which is the technology indicator directly relates to the benefits of adopting e-Ticketing technology in highway construction. This group has a co-efficient of 0.326 and has a total of 7 indicators which correspond to the outcomes of implementing e-Ticketing technology. The ratings of this group have been inverted to match with the ratings of occurrences (Figure 2). Hence, a low mean score signifies a higher importance level by the participants. Among the indicators used in the study “Inspectors can collect, review, and document more tickets” is ranked the highest with a mean score of 2.79 followed by “stakeholders can stay connected in real-time” with a mean score of 2.56. There is also a significant agreement among the participants that site hazards can be minimized, and inspectors can handle multiple projects with the use of e-Ticketing technology. Most repetitive procedures done in the field, such as collecting paper tickets from drivers/operators, estimating cumulative loads, documenting truck numbers, confirming tonnage, and reconciling tickets, may be easily semi-automated, therefore saving a substantial amount of time. Inspectors and engineers may utilize the time they save to conduct other important activities, such as quality control, which will help improve the performance of highways. Importantly, there is a persistent shortage of engineers and inspectors in the highway construction industry. Another advantage is greater monitoring efficiency, which is advantageous for area and district engineers. The area engineers can assign inspectors based on their needs and may remotely monitor the development of several projects.

8.7.2. e-Ticketing Assessment Tool

This EEI (e-Ticketing Effectiveness Index) can be used by researchers to develop tools and frameworks for e-Ticketing effectiveness in construction. The practitioners can also take advantage of the current study as the EEI will help them make better decisions making based on the fact that the last equation calculated the final value as to how the organization is performing and will perform in terms of e-Ticketing adoption. The result can be compared with the Likert scale for the indicators used (i.e., 1 being the highest score and 7 being the lowest score in terms of frequency of events or agreement with the statements for e-Ticketing effectiveness). The highest possible score in each category (GCEI) is determined by multiplying the total number of points received by the maximum possible score for that category, which is a multiple of the number of indicators (7 on a 7-point scale). As an illustration, the highest possible score on the GCEI 1 Technology Indicators is 49 (7 x 7). The answer key for this worksheet has a maximum possible score of 119, and it follows a method that is the same for each Group. In order to take into account the significance of each group, the coefficients obtained by the EEI model are entered into the spreadsheet and multiplied by the highest possible score for each group. This allows the weight of each group to be taken into account. Consequently, the highest score for the e-Ticketing Adoption Readiness Index is 39.8 and the minimum value is 5.6. If the score obtained from the practitioners after inputting their values is close to the minimum value, then they must adopt e-Ticketing with highest priority.

If the scores obtained from the participants is close to the maximum score, then there is relative lesser effectiveness of implementing e-Ticketing. This study's e-Ticketing adoption readiness index (EARI) and assessment tool can serve as a realistic framework for evaluating an organization's preparedness to automate ticketing and material delivery procedures. Using Equation (7) and Table 8.9, practitioners may evaluate the preparedness to incorporate e-Ticketing technology. The suggested model may also be utilized to offer practitioners with a method for comparing two or more e-Ticketing technology aspects being considered for adoption.

Table 0-9 e-Ticketing adoption assessment tool

Indicators	**Participant rating**	**Group max score**	**Category coefficient**
Ticketing Process Indicators			
Errors in reconciliation Errors in cumulative tonnage Lost paper tickets Inaccurate ETA of material delivery trucks Excessive wastage of material One ticket being accounted for multiple times Wrong ticket sent with the load		49	0.346
Organizational Indicators			
Workforce shortage of engineers and inspectors	Select rating	21	0.328
Schedule delay due to operational challenges	Select rating		
Cost overruns due to quality issues	Select rating		
Technology Indicators			
Manually entering ticket details can be automated.	Select rating	49	0.326
Documentation of billing and invoices can be automated	Select rating		
Increased morale and efficiency of inspectors	Select rating		
Inspectors/engineers can handle multiple projects	Select rating		
Site hazards can be prevented to a certain extent	Select rating		
All stakeholders can stay connected in real-time	Select rating		
Inspectors can collect, review, and document more tickets	Select rating		
Minimum/Maximum score			5.6 / 39.80
e-Ticketing adoption readiness score			Total score
Percentage to minimum score			Change%

8.8. Conclusion, Limitations, and Recommendation for Future Studies

Improved performance and productivity in highway construction is the top priority for all stakeholders involved. However, achieving high performance has been difficult because of resistance to innovation adoption. The study provided a method for building an e-Ticketing adoption effectiveness for assessing an organization's readiness to embrace automation. To promote the deployment of e-Ticketing in the highway construction industry, a framework based on CEIs and FSE analysis is utilized in the study The study found 17 CEIs from the three key indicator groups: technological, organizational, and ticketing process. Based on the responses on indicators, a coefficient was created to present a realistic method for evaluating the EEI of an organization. State DOTs and general contractors can utilize the assessment tool to gain a precise understanding on adoption priority within their organization. The developed index and model will serve as an essential start-point for creation of other models related to material supply and inspection processes.

This study had certain limitations that can be addressed in future research studies. Due to the construction industries' unwillingness to engage in survey-based studies, the sample size was limited. Future research should explore the advantages of electronic inspection methods and design a similar decision-making model incorporated in this study that will enable agencies to increase their operational efficiency. In addition, academic researchers can investigate expanding studies on technology adoption preparedness, such as the incorporation of robotics, artificial intelligence, digital as-builts, and other fields in the construction of highway infrastructure

CHAPTER 9

CONCLUSION, LIMITATIONS, AND FUTURE WORK

9.1. Conclusion

In the development of transportation infrastructure projects, digitalization has encountered major setbacks. Most industries, including manufacturing, entertainment, and services, are developing solutions in response to quality, safety, and production concerns, resulting in significant performance and quality benefits. The present study aims to increase the overall efficiency in the delivery of highway infrastructure projects through the adoption of e-Ticketing technology. Also, 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.

Departments of transportation (DOTs) and the private sector both invest heavily on printing, delivering, sorting, and archiving paper tickets. The paper-based technique necessitates an in-person ticket collector to receive tickets from truck drivers, record tonnage and location, compute yield, and present daily summaries. From the transcripts, it can be deduced that the timesaving can vary from 30 minutes to 120 minutes depending upon the size of the project which is directly proportional to the number of tickets generated. The state DOTs can allocate the personnel who are handling tickets to much significant operations thereby solving the workforce shortage problem while also saving quantifiable costs to the organization. e-Ticketing can alleviate many of the industry’s challenges by helping those struggling with declining workforces, cost overruns, and schedule delays. The extensive analysis of semi-structured interview transcripts suggests 3 key aspects that will assist stakeholders in transitioning from pilot tests to full-scale implementation. Firstly, the DOTs must mandate the use of e-Ticketing systems throughout the state by purchasing the software to reap the complete benefits of the technology. This can only be achieved by decoupling fleet management (GPS transponders, geofences, and geolocation) from e-Ticketing application, thereby taking off 90% of the investment cost of the technology. The state DOTs need to have a single source of documentation which will have APIs built into the material plant and into the state-owned documentation software. Secondly, in areas with no internet connectivity, QR codes must be used as a mode to transfer data from material plant to the on-site inspector mobile application. This will play a major role in the technology implementation as the paper tickets handover stops at the truck operator and will not complete its life cycle. Thirdly, due to the pandemic's faster deployment of e-Ticketing technology, diverse levels of implementation and regulations have emerged, which vary greatly from state to state. Due to the platform's partial implementation during the peak Covid-19 period, some state DOTs have not fully utilized the platform's capabilities and have merely emailed image/pdf versions of tickets. This has resulted in a widespread misconception of the platform's true capabilities and its ability to simplify and automate day-to-day operations. DOTs that have adopted guidelines only for the purpose of social distancing should also look at the other benefits of e-Ticketing and start pilot programs

The study provided a method for building an e-Ticketing adoption effectiveness for assessing an organization's readiness to embrace automation. To promote the deployment of e-Ticketing in the highway construction industry, a framework based on CEIs and FSE analysis is utilized in the study The study found 17 CEIs from the three key indicator groups: technological, organizational, and ticketing process. Based on the responses on indicators, a coefficient was created to present a realistic method for evaluating the EEI of an organization. State DOTs and general contractors can utilize the assessment tool to gain a precise understanding of adoption priority within their organization. The developed index and model will serve as an essential start-point for the creation of other models related to material supply and inspection processes.

The goal of the survey questionnaire was to quantify the effect that e-Ticketing technology would have on inspectors' productivity, rank the limitations and gain stakeholders' perception on the critical effectiveness indicators. The participants estimated that the implementation of an e-Ticketing platform would save each inspector between 30 and 90 minutes per day that would be required for manually scanning paper tickets into document management software, matching them up with the invoices, paying invoices, and calculating cumulative loads manually. From the analysis of the survey responses, it is evident that the productivity of inspectors and engineers is directly proportional to the number of tickets produced at the job site, which is a function of project duration or project cost. The increase in their productivity is directly related to the amount of time saved per day per project by using e-Ticketing technology. The study also investigated whether implementing e-Ticketing can reduce the number of inspectors required for highway construction projects, and it was deduced that for projects that require more than one inspector, e-Ticketing would eliminate approximately 25% of the inspector workforce. The limitations of "internet inaccessibility at remote locations," "challenges in bidding and agreements," "failure to train employees regarding the use of the systems," and "lack of support and hesitation from stakeholders" are significantly affecting the implementation of e-Ticketing technology.

9.2. Limitations

Despite its numerous advantages, this study has a few limitations. First, the semi-structured interview and survey were conducted during the time of Covid-19. As the technology has the potential to reduce hum-to-human interaction, most of the participant's perception of the technology was inclined toward social distancing guidelines and regulations. Some of the participants believed that transferring photocopies of tickets is e-Ticketing. Second, the study relied on the geographical context of only the United States of America.

9.3. Future Work

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. First, 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. Second, future studies should consider integrating material testing and inspection test results into a single e-Ticketing platform. The massive amount of metadata may be utilized to create prediction models for cost reduction and quality assurance. If all construction data is entered into a single database, from contract to material delivery to project completion, it will help in further analysis of the raw data, provide suitable tender pricing, and create a baseline for transportation projects, decreasing cost overruns and schedule delays. Third, the decision-making model incorporated in this study can be further extended into other proven underutilized technologies that will enable agencies to increase their operational efficiency. In addition, the researchers and practitioners should consider the possibility of integrating digital as-builts and electronic inspection with e-Ticketing technology.

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APPENDIX A

SEMI-STRUCTURED INTERVIEW GUIDE

We are conducting an interview to measure the time and cost savings due to the implementation of e-Ticketing and other advanced technologies in construction projects. Your expertise and feedback would be valuable to our research. There are no perceived risks for participating in the study. There are no alternatives for this research project, but you may quit at any time. Any identifiable information will be kept confidential with the access limited to the research team. For questions or concerns contact the UTA Research Office at 817-272-3723 or regulatoryservices@uta.edu. It will take about 30 to 45 minutes to participate in this research, and your participation is completely voluntary.

Semi-structured interview guide

<u>Introduction</u>

1. What is the organization you work for and name your role?
2. What are the total years of experience in the highway industry?
3. Have you or your organization used e-Ticketing in any of the projects?
    - When was the first initiative towards e-Ticketing taken?

<u>Problems in Highway Construction</u>

1. Does your organization face shortage of inspectors and engineers? If yes, what are the key factors affecting this? Does the use of e-Ticketing solve shortage or workforce
    - Does your organization hire third party inspection agencies?
2. Has there been safety concerns related to collecting paper tickets and inspection process? If yes, please explain how? What are the safety-related concerns?
3. Did your organization face safety issues and challenges at the time of peak Covid-19 and lockdowns?
4. Does your organization store the paper tickets collected by inspectors and engineers in a cloud database that can be used for future insights?
5. Does your organization specifically have administrative staff to store/manually enter data/document the tickets, test results and invoices? If yes, how many of them does each district have/how many each project have/or can you quantify their number?
6. How does live location of material trucks affect the daily operation in the process of paving?
7. Did your organization face issues related to material ticket documentation and billing which led to legal issues and claims?
8. Does the inaccuracy in billing, reconciliation and invoices affect the project completion date? If yes, please explain how.
9. Briefly explain the inspection process of material testing and asphalt paving operations at your organization.
    I. Types of tests
    II. Equipment used
    III. Paper/digital checklist
    IV. Digital record of pictures
10. What is your opinion on internet connectivity at highway construction sites? Have you seen an increase in connectivity over the last 5 years?
11. How frequently does your organization face excessive wastage of material? If yes, what is the reason behind this?

<u>e-Ticketing Technology Adoption</u>

1. Did your organization accelerate its focus on implementing e-Ticketing technology at the time of Covid-19?
2. What was the primary reason for implementing e-Ticketing at your organization?
3. During the implementation phase, did your organization consider building in-house e-Ticketing application?
4. Does the real time data feed of materials provide valuable insights into daily operations? If yes, how does it help in optimizing day-to-day operations?
5. How does a ticket get generated and accepted in e-Ticketing software? (Use of Geofences and GPS, Scanning the number plates of trucks, manually accepting the tickets?)
6. How did your organization handle the training of employees relating to the use of e-Ticketing software?
7. Does the use of e-Ticketing platform help inspectors, engineers, operators, material vendors, contractors, and owners to stay connected and informed at the same time? If yes, how does it help in optimizing the day-to-day operations?
8. Do you agree that inspector and engineers can sort/review/document significantly more tickets with the use of e-Ticketing application? If yes, can you quantify the increase and the reason behind it.
9. What percent of project cost can be saved by implementing e-Ticketing in a highway and bridge project? Has the savings been quantitatively notified at your organization?
10. What are the concerns related to data security and integrity? How does this affect the implementation process?
11. Have your organization considered mandating the use of e-Ticketing software throughout the state? What are the advantages and hindrances in this process?
12. Do you agree that there is a significant rise in productivity of engineers and inspectors when using e-Ticketing application?

Strategies and Technology Integration

1. Has your organization considered transferring ticket data through Bluetooth/NFC/Airdrop in locations where there are connectivity issues?
2. Has your organization included inspection and testing results in the e-Ticketing application?
3. What are the advantages of having formattable digital checklist which is integrated into e-Ticketing platform?
4. What are the advantages of creating as-builts or digital twins of highway projects?
5. Has your organization used intelligent compaction or infrared enabled pavers in highway construction? If yes, what is your opinion on integrating it with e-Ticketing application, and how will it help to simplify the processes.

APPENDIX B

SURVEY QUESTIONNAIRE

Dear Participant,

We are writing to ask for your participation in a research survey at the University of Texas at Arlington (UTA) aiming to measure the time and cost savings due to the implementation of e-Ticketing and other advanced technologies in construction projects. Your participation in the survey is voluntary, and your responses are completely confidential. This survey will take about 15 minutes.

This research project is sponsored by the US Department of Transportation (USDOT). We highly appreciate your contribution to this unique effort. Your personal information will not be represented in the report or in any data available to the public. Please continue if you voluntarily agree to participate in this research.

This research is carried out under the supervision of Dr. Sherri Kermanshachi, assistant professor in the Department of Civil Engineering and Director of the Resilient Infrastructure and Sustainable Environment (RISE) Lab at the University of Texas at Arlington. If you have any questions, you can contact the project PI, Dr. Sherri Kermanshachi at sharareh.kermanshachi@uta.edu or UTA Research Office at regulatoryservices@uta.edu.

Thank you very much for your participation.

Demographic questions

1. Please specify your experience years in construction industry:

1. 1. Less than 2 years
2. 2. 2 - 5 years
3. 3. 5 – 10 years
4. 4. 10 - 15 years
5. 5. 15 - 20 years
6. 6. 20 - 25 years
7. 7. Above 25 years

2. Please specify your position in construction industry:

1. 1. Inspector
2. 2. Project manager
3. 3. Field materials engineer
4. 4. Site engineer
5. 5. Material hauler/dispatcher
6. 6. Equipment operator, truck operator
7. 7. Technology implementation administrator
8. 8. Other

3. Please specify the type of construction sector you are involved in:(Select as much as applies)

1. 1. Highway, Roadway
2. 2. Bridges
3. 3. Water Infrastructure
4. 4. Industrial Construction
5. 5. Heavy Construction
6. 6. Other

4. Please specify the organization you are working at:

1. 1. State Department of Transportation (DOT)
2. 2. Contractor
3. 3. Material supplier
4. 4. Technology provider/vendor
5. 5. Federal Highway Administration (FHWA)
6. 6. Consulting/Engineering firm
7. 7. Other

5. Please specify your state:

1. 1. -select option-
2. 2. Alabama
3. 3. Alaska

4. 4. Arizona
5. 5. Arkansas
6. 6. California
7. 7. Colorado
8. 8. Connecticut
9. 9. Delaware
10. 10. Florida
11. 11. Georgia
12. 12. Hawaii
13. 13. Idaho
14. 14. Illinois
15. 15. Indiana
16. 16. Iowa
17. 17. Kansas
18. 18. Kentucky
19. 19. Louisiana
20. 20. Maine
21. 21. Maryland
22. 22. Massachusetts
23. 23. Michigan
24. 24. Minnesota
25. 25. Mississippi
26. 26. Missouri
27. 27. Montana
28. 28. Nebraska
29. 29. Nevada
30. 30. New Hampshire
31. 31. New Jersey
32. 32. New Mexico
33. 33. New York
34. 34. North Carolina
35. 35. North Dakota
36. 36. Ohio
37. 37. Oklahoma
38. 38. Oregon
39. 39. Pennsylvania
40. 40. Rhode Island
41. 41. South Carolina
42. 42. South Dakota
43. 43. Tennessee
44. 44. Texas
45. 45. Utah
46. 46. Vermont
47. 47. Virginia
48. 48. Washington
49. 49. West Virginia
50. 50. Wisconsin
51. 51. Wyoming

6. Do you work in construction sites, or frequently visit construction fields?

1. 1. Yes
2. 2. No

7. Please specify the type of material supply you come across in your daily work:(Select as much as applies)

1. 1. Asphalt
2. 2. Concrete
3. 3. Aggregates
4. 4. Recycled material
5. 5. Soil
6. 6. Building blocks

7. 7. Structural steel and rebar
8. 8. Other

e-Ticketing technology in construction

8. How familiar are you with the concept of e-Ticketing and fleet management in construction industry?

	Not at all familiar	Slightly familiar	Moderately familiar	Very familiar	Extremely familiar
e-Ticketing	❑	❑	❑	❑	❑
Fleet Management	❑	❑	❑	❑	❑

9. How agree are you with the following statements?

	Strongly disagree	Disagree	Somewhat Disagree	Neither Agree or Disagree	Somewhat Agree	Agree	Strongly Agree
Manually entering ticket details require a significant level of effort and needs to be automated.	❑	❑	❑	❑	❑	❑	❑
Adding cumulative loads require a significant level of effort and needs to be automated.	❑	❑	❑	❑	❑	❑	❑
Material inspection such as air content, slump and water added needs to be digitalized.	❑	❑	❑	❑	❑	❑	❑
Manually recording mat temperatures during asphalt paving needs to be automated	❑	❑	❑	❑	❑	❑	❑
Documentation of billing and invoices needs to be automated	❑	❑	❑	❑	❑	❑	❑
There is a threat to the safety of inspectors while collecting load paper tickets in transportation infrastructure projects	❑	❑	❑	❑	❑	❑	❑

10. How frequently does your organization face the following challenges?

	Never	Rarely	Occasionally	Sometimes	Frequently	Usually	All the time
Errors in cumulative tonnage	❑	❑	❑	❑	❑	❑	❑
Errors in reconciliation	❑	❑	❑	❑	❑	❑	❑
One ticket being accounted for multiple times	❑	❑	❑	❑	❑	❑	❑
Wrong ticket sent with the load	❑	❑	❑	❑	❑	❑	❑
Lost paper tickets	❑	❑	❑	❑	❑	❑	❑
Inaccurate ETA of material delivery trucks	❑	❑	❑	❑	❑	❑	❑
Cost overruns	❑	❑	❑	❑	❑	❑	❑
Schedule delays	❑	❑	❑	❑	❑	❑	❑
Workforce shortage of engineers and inspectors	❑	❑	❑	❑	❑	❑	❑
Internet connectivity at sites	❑	❑	❑	❑	❑	❑	❑
Excessive wastage of material	❑	❑	❑	❑	❑	❑	❑

11. Has your organization ever used e-Ticketing technology in any of their projects?
    1. 1. Yes
    2. 2. No

12. Was the adoption of this e-Ticketing technology required by the project contract?
    1. 1. Yes
    2. 2. No

13. Please specify the number of projects your organization has completed using e-Ticketing under the contract:
    1. 1. 1 - 5 projects
    2. 2. 5 - 15 projects
    3. 3. 15 - 30 projects
    4. 4. 30 - 50 projects
    5. 5. 50 projects and more
    6. 6. N/A

14. Which stage is your organization in the process of implementing e-Ticketing?
    1. 1. Conception stage
    2. 2. Pilot tests
    3. 3. Partial implementation
    4. 4. Full scale implementation

15. Were you involved in the investment decision making process for e-Ticketing projects?
    1. 1. Yes
    2. 2. No

16. Please specify the total cost of the recent project you worked on which involved e-Ticketing:
    1. 1. 0 - $1M
    2. 2. $1M - $3M
    3. 3. $3M - $5M
    4. 4. $5M - $10M
    5. 5. $10M - $25M
    6. 6. $25M - $50M
    7. 7. $50M - $100M
    8. 8. $100M and above

17. Please specify the total duration of the project you worked on which involved e-Ticketing:
    1. 1. 0 - 3 months
    2. 2. 3 - 6 months
    3. 3. 6 - 12 months
    4. 4. 1 - 2 years
    5. 5. 2 years and more

18. How many inspectors would be needed without the adoption of e-Ticketing technology in this recent specific project?
    1. 1. -select option-
    2. 2. 1
    3. 3. 2
    4. 4. 3
    5. 5. 4
    6. 6. 5
    7. 7. 6
    8. 8. 7
    9. 9. 8
    10. 10. 9
    11. 11. 10
    12. 12. 11
    13. 13. 12

14. 14. 13
15. 15. 14
16. 16. 15 and more

19. How many inspectors were actually needed in this project after e-Ticketing adoption in this recent specific project?
1. 1. -select option-
2. 2. 1
3. 3. 2
4. 4. 3
5. 5. 4
6. 6. 5
7. 7. 6
8. 8. 7
9. 9. 8
10. 10. 9
11. 11. 10
12. 12. 11
13. 13. 12
14. 14. 13
15. 15. 14
16. 16. 15 and more

20. How much cost was saved due to adoption of the e-Ticketing technology in this recent specific project?
1. 1. 0 - $50,000
2. 2. $50,000 - $100,000
3. 3. $100,000 - $250,000
4. 4. $250,000 - $500,000
5. 5. $500,000 - $1 Million
6. 6. $ 1 Million - 5 Million
7. 7. 5 Million - 10 Million
8. 8. 10 Million and above

21. Please specify the cost of implementing e-Ticketing in your organization:
1. 1. 0 - $25,000
2. 2. $25,000 - $50,000
3. 3. $50,000 - $100,000
4. 4. $100,000 - $200,000
5. 5. $200,000 - $400,000
6. 6. $400,000 and more

22. Please specify the e-Ticketing vendor in your organization:
1. 1. HaulHub Technologies
2. 2. Fleetwatcher
3. 3. HCSS
4. 4. Connex
5. 5. Trux
6. 6. SoilConnect
7. 7. In-House application
8. 8. Other

23. Which of the following process is more prone to user related errors?
1. 1. e-Ticketing
2. 2. Traditional paper ticketing
3. 3. Not sure

24. How expensive/inexpensive have your organization felt in terms of cost of implementing e-Ticketing?

	Very Inexpensive	Inexpensive	Somewhat Inexpensive	Neutral	Somewhat Expensive	Expensive	Very Expensive
Cost of implementing E-ticketing	❑	❑	❑	❑	❑	❑	❑

25. Please specify the level of difficulty in training the employees regarding the use of e-Ticketing platform:

	Very Difficult	Difficult	Somewhat Difficult	Neutral	Somewhat Easy	Easy	Very Easy
Level of difficulty in training employees	❑	❑	❑	❑	❑	❑	❑

26. How important are the following features of e-Ticketing:

	Not at all important	Low importance	Slightly important	Neutral	Moderately important	Very important	Extremely important
Real-time material data	❑	❑	❑	❑	❑	❑	❑
Flexible sorting of tickets	❑	❑	❑	❑	❑	❑	❑
Data related to inspection tests and reports	❑	❑	❑	❑	❑	❑	❑
Digital inspection checklist	❑	❑	❑	❑	❑	❑	❑
Security of material data (Data integrity)	❑	❑	❑	❑	❑	❑	❑

27. How agree are you with the following statements?

	Strongly Disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Implementation of e-Ticketing will make the work process simpler for all the stakeholders in the project	❑	❑	❑	❑	❑	❑	❑
E-ticketing can help reduce human-to-human interaction	❑	❑	❑	❑	❑	❑	❑
Project engineers/inspectors/ managers can handle multiple projects smoothly with the e-Ticketing systems	❑	❑	❑	❑	❑	❑	❑
Site hazards can be prevented to a certain extent in road/bridge construction with the use of e-Ticketing systems	❑	❑	❑	❑	❑	❑	❑
e-Ticketing will help inspectors, engineers, operators, material vendors, contractors and owners to stay connected and informed at the same time.	❑	❑	❑	❑	❑	❑	❑
With e-Ticketing technology, inspectors and engineers can collect, review, and document significantly more tickets per day than the traditional paper ticketing process.	❑	❑	❑	❑	❑	❑	❑

Day-to-day operations at site

28. How many man-hours of inspectors can be saved per day per project by automating the process of printing, collection, acceptin storing, and sorting of paper tickets?

1. 1. 30 minutes or less
2. 2. 30 minutes to 1 hour
3. 3. 1 – 2 hours
4. 4. 2 - 3 hours
5. 5. 3 - 4 hours
6. 6. 4 hours or more

29. Please specify the time to order material from the supplier and receive confirmation:

1. 1. 0 – 5 (minutes)
2. 2. 5 – 10 (minutes)
3. 3. 10 – 15 (minutes)
4. 4. 15 minutes and above

30. On an average, how many paper tickets does your organization produce/collect/sort in a single day?

1. 1. Paper tickets are not used
2. 2. 0 - 2
3. 3. 3 - 5
4. 4. 6 - 10
5. 5. 11 - 20
6. 6. 21 - 30
7. 7. 31 and more

31. Please specify the time required per day to manually scan a day's batch of tickets into the document management system:

1. 1. Less than 15 minutes
2. 2. 15 - 30 minutes
3. 3. 30 - 60 minutes
4. 4. 1 - 2 hours

5. 5. 2 - 4 hours
6. 6. 4 hours and more

32. How long does it take to pay invoices?

1. 1. Less than 15 minutes
2. 2. 15 - 30 minutes
3. 3. 30 - 60 minutes
4. 4. 1 – 2 hour
5. 5. 2 hours and more

Limitations

33. How agree are you that the following are the limitations of implementing e-Ticketing platform:

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Internet accessibility issues	❑	❑	❑	❑	❑	❑	❑
No standardized format of data files	❑	❑	❑	❑	❑	❑	❑
Challenges in bidding and agreements	❑	❑	❑	❑	❑	❑	❑
Failure to train employees regarding the use of these systems	❑	❑	❑	❑	❑	❑	❑
Lack of support and hesitation from interdependent parties	❑	❑	❑	❑	❑	❑	❑
Lack of adequate funding to implement the system	❑	❑	❑	❑	❑	❑	❑

34. How important are the following additional features of e-Ticketing?

	Very Unimportant	Unimportant	Somewhat Unimportant	Neutral	Somewhat Important	Important	Very Important
Chatbot and live assistance for operators	❑	❑	❑	❑	❑	❑	❑
Automated dispatch and delivery alerts	❑	❑	❑	❑	❑	❑	❑
Integration with fleet management for real-time material load location and ETA	❑	❑	❑	❑	❑	❑	❑
Sensors for automated temperature monitoring	❑	❑	❑	❑	❑	❑	❑
Drone inspections in remote locations	❑	❑	❑	❑	❑	❑	❑
Availability of as-built drawings and blueprints in e-Ticketing application	❑	❑	❑	❑	❑	❑	❑
Formattable inspection checklists	❑	❑	❑	❑	❑	❑	❑
Sensors for automated compaction monitoring	❑	❑	❑	❑	❑	❑	❑

35. Which of the following stakeholders are less supportive of the e-Ticketing adoption:

1. 1. Material provider/Vendor
2. 2. Project Owner

3. 3. Governmental agencies
4. 4. General contractor
5. 5. Sub contractors

If you are interested in a virtual interview about e-Ticketing, Please provide your email address (Optional)