Transportation Consortium of South-Central States

Tran-SET

Solving Emerging Transportation Resiliency, Sustainability, and Economic Challenges through the Use of Innovative Materials and Construction Methods: From Research to Implementation

Effectiveness Assessment of e-Ticketing Technology in Construction of Transportation Projects

Project No. 21TSUTA02

Lead University: The University of Texas at Arlington

Final Report

August 2022

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16. Abstract

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. 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, review section is followed by a semi-structured interview and survey results. 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. 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.

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APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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ACRONYMS, ABBREVIATIONS, AND SYMBOLS

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

EXECUTIVE SUMMARY

Cost and schedule overruns, limited funding, inspector shortages, and a scarcity of workforce in remote areas are beleaguering state departments of transportation (DOTs) at a time when they are constructing and managing more highway and bridge construction projects than ever before. This exacerbates the number of disputes about the quality of the end product and highlights the need to streamline daily operations. The construction industry has earmarked significant resources for e-Construction, to automate many of the time-consuming tasks performed daily and reduce the amount of paperwork by implementing electronic ticketing (e-Ticketing), which digitizes the transfer of tickets for materials such as asphalt and concrete. Despite its benefits, however, most state departments and agencies have been unwilling to transition to the new technology.

Since early 2013, several states have pilot tested e-Ticketing but have abandoned it for various reasons. A few DOTs and general contractors have implemented it to increase their workforce's productivity and efficiency, but most are still using the conventional paper methods. No studies have identified the reasons for the delays in transitioning to the technology or have developed a framework to reveal the platform's full potential, quantified savings, and strategies for overcoming the barriers to its implementation. Therefore, the goals of this study were to (1) identify the inefficiencies in the conventional paper ticketing process that can be overcome by specific technology; (2) identify the benefits of e-Ticketing technology by quantifying the reductions in inspection staff and the amount of time savings; (3) develop a multi-criteria decision-making model tailored for DOTs and general contractors that will help them implement an e-Ticketing platform; (4) identify and rank the major limitations to implementing e-Ticketing technology and suggest strategies to overcome them.

Changes in technological trends in highway construction relating to material tracking, inspection, and digitization were qualitatively analyzed using meta-synthesis and interpretative analytical techniques to achieve the study's objectives. Semi-structured interviews were conducted with DOT employees, general contractors, material vendors, and software vendors and were analyzed with an inductive thematic analysis approach, using MAXQDA software. Later a survey was conducted to elicit the opinions of highway construction stakeholders on critical readiness indicators, benefits, adoption levels, and the future integration of e-Ticketing technology. Responses were received from 20 state DOTs and were used to categorize the critical effectiveness indicators and rank the operational challenges, using the Relative Importance Index. The study analyzes 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 e-Ticketing platforms vary widely across states and established 17 indicators that directly influence its implementation. An analysis of the interview transcripts revealed the inefficiencies in conventional ticketing, the key reasons for delayed implementation of e-Ticketing, and strategies to overcome the obstacles. A comparison was made between the number of inspectors needed prior to and after the implementation of e-Ticketing and revealed that for projects requiring multiple inspectors, e-Ticketing could reduce the workforce by 25%. The study's findings will provide practitioners with an assessment tool that will enable them to gain insights into the priority levels in implementing the e-Ticketing technology and help DOT decision-makers and engineers build a standard e-Ticketing platform, establish guidelines and implement rules, reduce project costs, provide initial funding, execute pilot testing, improve inspector safety, and complete projects in a timely and efficient manner. The e-Ticketing Effectiveness Index (EEI) model will provide the DOTs and general contractors with a decision-making assessment tool that will facilitate widespread adoption of the technology.

1. INTRODUCTION

1.1. Background

Governments allocate substantial financial resources to constructing and improving road networks, as they are critical components of a nation's transportation system . Digitization is paving the way for significant changes that will have far-reaching implications *(1, 2)*, and some of the industries, including manufacturing, entertainment, and services, are employing emerging technologies in response to quality, safety, and production issues and are seeing significant gains in performance and quality *(3)*. There has been resistance to digitization in the construction of transportation infrastructure projects, however, despite the quality, safety, and budget issues that impact projects' operating lives and nonconformance quality issues that can result in penalties that are associated with reworks and cost and schedule overruns.

The FHWA defines e-Construction as ‘‘the creation, review, approval, distribution, and storage of highway construction documents in a paperless environment.” An e-Ticket is an electronic document that can be stored on a mobile phone or computer as proof of confirmation, delivery, and reservations for any event or activity. It encompasses a wide range of technologies and processes designed to improve efficiency and safety by eliminating the need to handle and track paper documents and has shown promising results in solving problems incurred by the traditional methods of processing paper tickets (e.g., unsafe work environments for workers and inspectors, manual data entry, and delayed invoicing and payments) through paperless administration and workflows.

Stakeholders and consumers of many industries, such as event management, airlines, public transport, and entertainment, have realized numerous advantages by using e-Ticketing *(4-6),* but most state DOTs have not implemented it for a variety of reasons, including its high investment cost. Information related to the use of e-Ticketing and material tracking technology in the highway construction industry *(7-10)* has been synthesized; however, no one has created a viable body of knowledge that details the time savings, increase in inspectors' productivity, and cost savings realized by its implementation. Consequently, the existing literature does not quantify the benefits of the technology, which has led to delays in the implementation process. An assessment tool is needed to help DOTs frame their reasons for implementing the technology, and a decision-making model is required for them to fully understand its potential benefits.

1.2. Problem Statement

The highway construction industry suffers from a variety of problems, including shortages of inspectors and engineers, quality issues, document management inefficiencies, cost overruns, injuries/fatalities, and schedule delays *(11-14)*. 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, the number of 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 *(15)*. Factors such as low pay, budget cuts, and a booming private industry have led people to leave their jobs in the public sector. Qualified personnel are retiring and are either being replaced by less-experienced personnel who are taking on more responsibilities earlier in their careers or are not being replaced at all.

Producing, sorting, recording, and archiving paper tickets for bills for materials, testing results, inspection records and a variety of other documents are costly and time-consuming tasks for state DOTs and contractors *(16)*. Some state DOTS have administrative staff whose responsibility is to scan each ticket into a software management system, but this requires re-entering the information; otherwise, they remain in a cumbersome and difficult-to-access paper format. The paper-based technique lacks traceability for materials, and it is not unusual for tickets to be lost or damaged, which may result in delayed billing and a waste of considerable time and resources. Illegible data on paper tickets is also a concern, as most asphalt plant owners are still using DOT matrix printers with carbon copies. In addition to the disadvantages of paper tickets mentioned above, the practice of physically collecting tickets from delivery trucks exposes inspectors to dangerous conditions during paving projects and highway construction inspectors to a variety of potentially dangerous scenarios on the job site, from strolling alongside traffic to boarding trucks to obtain tickets.

2. OBJECTIVES

This following objectives were formulated to evaluate the effectiveness of e-Ticketing technology in highway construction.

- Identify inefficiencies in the conventional paper ticketing framework and suitable technology to overcome them.
- Identify the benefits of e-Ticketing and quantify the reduction in inspection staff and time savings realized by implementing the technology.
- Identify and rank the major limitations of implementing e-Ticketing technology and suggest suitable strategies for overcoming them.
- Develop a multi-criteria decision-making model for implementing an e-Ticketing platform, based on the needs and objectives of the state DOTs and general contractors.

3. LITERATURE REVIEW

3.1. Digitization and Computing Technology in Highway Construction

Transportation agencies are taking advantage of the multiple benefits of e-Construction technology by transitioning from their conventional, inefficient, paper-based document management procedures. This section provides the framework and scope of the focus of this research on digitization in highway construction and briefly discusses the notion of digitization in the construction sector and highway construction issues that are connected to and will affect the industry's acceptance and implementation of e-Ticketing technology.

Transportation agencies are beginning to use e-Construction technology rather than the traditional inefficient, paper-based document management methods *(17)*, and the greater integration of information afforded by digital project delivery has the potential to benefit construction partnerships and stakeholders. The Federal Highway Administration (FHWA) is a staunch supporter of the implementation of electronic construction in the transportation sector and recommends that electronic plans, as-builts, reviews, approvals, contracts, communication, quality assurance, and material ticketing be included in the e-Construction framework *(18)*. Their Every Day Counts initiative incentivizes quicker completion of projects, higher levels of safety, and lower levels of damage to the environment *(19)*.

While the departments of transportation in a few states are conducting simultaneous pilot tests of newly created technologies, many others have already put certain components of e-Construction into practice *(20)* and are realizing its advantages, including faster payment transactions at every level, faster project delivery, increased organizational efficiency, and elimination of manual documentation and data entry. The most significant constraint to executing an e-Construction system is the cost of installation *(21)*. The majority of them are available as commercial off-the-shelf software (COTS), the license for which is invoiced annually. Training personnel and the buy-in of contractors and/or subcontractors are further obstacles.

Road infrastructure digitalization may be classified into two types according to Cruz and Sarmento: asset-related and service-related *(1)*. This research focuses primarily on asset-related digitalization, as computing technologies are vital to streamlining the processes in the design and construction phases of highway infrastructure. In the construction sector, computing technology is divided into two categories: (1) automation and (2) information and communications technology (ICT) *(22)*. 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 and emphasizes its capability for providing infrastructure support services. Figure 1 illustrates the hierarchy of digitization in the construction industry.

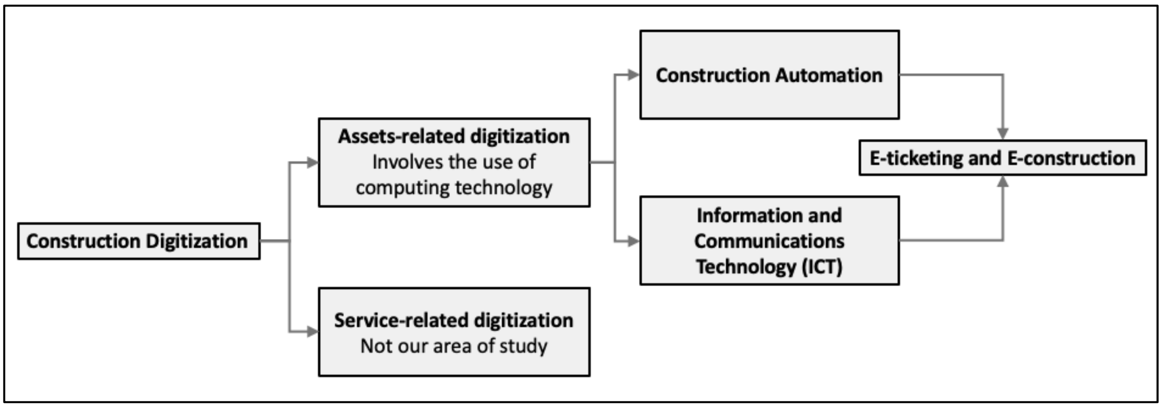

Figure 1. Hierarchy of digitization in the construction industry

3.2. Constraints and Challenges Encountered in Highway Construction

The transportation industry suffers from shortages of skilled labor and other types of workers, final project quality issues, document management, cost overruns, injuries/fatalities, and schedule delays *(11, 13)*. 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 of 40 state DOTs, from 2000 to 2010, the number of state-managed highways increased 4.10% and the number of full-time employees dropped by 9.68%. Most construction projects have cost and schedule overruns *(23)* that can be caused by the cost of utilities, damage resulting from weather, delays of material delivery, quality issues, and/or material reconciliation and can result in construction expenses exceeding the budget and projects being delayed. Over the course of a project, a contractor must adhere to 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 most of the work takes place in the field, these documents are frequently paper-based rather than electronic and must either be moved to an electronic system that requires re-entering the information or remain in a burdensome and difficult-to-retrieve paper format.

3.3. e-Ticketing Technology Overview

The FHWA defines e-Ticketing as a software platform that automates the real-time recording and transfer of information for materials as they are moved from the plant to the construction site. An e-ticket is an electronic document that can be stored in a mobile phone or 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 *(4, 5, 24)*. Although some industries, including the construction industry, are still using paper tickets, it is predicted that the number of industries that use e-Ticketing will rise over time *(25, 26)*.

As shown in Figure 2, TruckIT is a provider that serves as an example of how e-Ticketing would work for construction projects. Fleets of trucks are packed with materials at the plant and weighed, and electronic tickets record the types of 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, as it is assumed that its only benefit is that it can be used as proof of delivery without exposing inspectors and project engineers to the hazards of performing the tasks manually. 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 *(27)*.

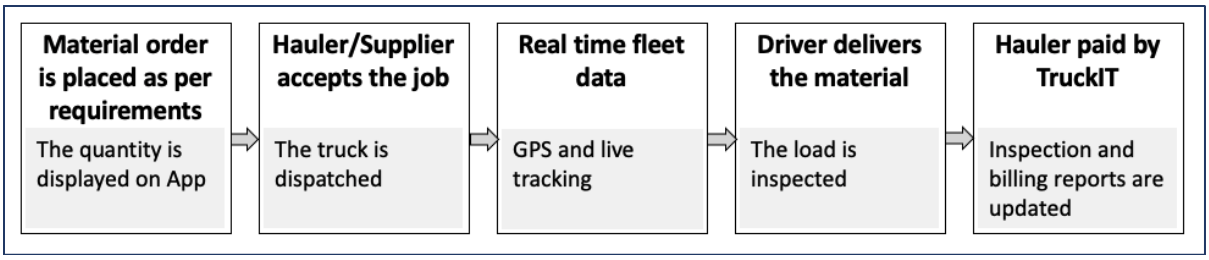

Figure 2. Process of material delivery adopted by TruckIT

3.4. Key Technologies Used in e-Ticketing

Combined GPS and GIS technology produces a fleet management system that traces haul routes, the estimated time of arrival (ETA), and tonnage and help contractors and managers balance and match their equipment appropriately with projects *(27, 28)*. 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 reduced 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 *(29, 30)*. The main components of an effective electronic ticketing system are depicted in Table 1. Barcodes/QR codes are used in all sectors of operations and are clearly employed in day-to-day operations, as they can be transformed into legible pdf texts/invoices/billing/reports. The use of radio frequency identification (RFID) for material delivery has been investigated by various scholars and has shown to be helpful in tracking goods on railway cars *(31-33)*; in the industrial 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 1. Key Technologies Used in e-Ticketing Systems

Technology	Description	Authors
Barcodes	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.	*(34, 35)*
Radio Frequency Identification	RFID 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.	*(24, 36-38)*
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.	*(8, 39, 40)*
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 civil construction and materials industry.	*(41, 42)*

3.5. 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 and can be important for guaranteeing that perishable materials, like concrete and asphalt, arrive at the right location at the right time. It is therefore important to adopt integrated technology tools as soon as they become available to take advantage of the more resourceful and efficient ways of tracking and controlling the quality of material while it is in transit. The current study analyzes the impacts of adopting e-Ticketing in three broad categories: cost and duration, workforce safety, and stakeholders.

3.5.1. Impact of e-Ticketing on Project Cost and Duration

The conventional paper ticketing process for handling materials for transportation projects is inefficient and negatively impacts the cost and duration of projects *(44)*, but transitioning to digitization platforms such as e-Ticketing and integrating them with existing technologies can open a wide array of opportunities in the construction material delivery and paving industries *(38, 44)*. Raw materials and equipment are key components of any construction activity and account for about half the cost of a project, and the rate at which they are used is directly proportional to the growth of the project. Table 2 shows the impact of implementing e-Ticketing on the cost and length of construction projects. With the increased demand for sound 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 *(45-47)*.

Importing these novel technologies into the e-Ticketing platform can render enormous benefits. For example, automated drones can be used in conjunction with 4D building information modelling to assess project progress and 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.

Table 2. Benefits of e-Ticketing for Cost and Duration of Projects

Category	Description	Authors
Time Savings	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.	*(44, 51)*
Operations	One of the major benefits 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 and results in their being more cost-effective.	*(9, 52)*
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 to reduce the number of manhours and duration of the project.	*(53, 54)*

3.5.2. Impact of e-Ticketing on Workforce Safety

Technology applications are safer and more efficient than many conventional methods. Figure 3 compares the view from the driver's seat of a truck with the 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 3.

Figure 3. Driver's view of inspector/worker *(48)*

The conventional method of measuring mat temperatures with handheld guns is a waste of human resources and dangerous for inspectors who are working in high-traffic areas *(10, 49)*, but using thermal infrared technology that is mounted on a paver to provide continuous temperature readings accomplishes the task and eliminates problems. The Texas Department of Transportation was the first DOT to test this technology and introduced it in 2000. Other examples are 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 managing multiple projects simultaneously *(50)*.

Table 3. Safety Benefits of e-Ticketing

Category	Description	Authors
Social Distancing	Safety was the most important reason that government entities and private companies shifted to e-Ticketing during the pandemic, and DOTs and private trucking firms are discovering that e-Ticketing keeps operators, inspectors, and other employees safer and expedites daily operations.	*(51, 55)*
Safety	The most visible advantage of e-Ticketing is the reduction in the number of accidents and hazards caused by vehicular traffic. Replacing human inspectors with technology eliminates the concerns about safety-related hazards that are encountered while performing inspections on high-speed and highly traveled highways.	*(18, 56-58)*
Reduced Liability	First responders are able to act quickly in the face of accidents and emergencies, as they are provided with the exact location and time of the accident.	*(8, 52)*

3.5.3 Impact of e-Ticketing on Stakeholder Interest

The adoption of any new technology requires an initial investment, but the benefits of e-Ticketing are many, as shown in Table 4. Stakeholders, ranging from investors to employees and customers, reap many advantages, including the elimination of lost paper tickets, which minimizes disputes over quantities at the time of billing and reconciliation. Training is vital for all those involved and helps the employees experience the benefits first-hand.

Table 4. 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 facilitates maintenance, operations, and asset management of future projects.	*(43, 51)*
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 manufacturing plants; monitors the temperature for laying concrete; tracks cumulative tonnage and waste generation and	*(35, 59)*

	provides information for line graph reports with a percentage of the data in real time.	
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 system. (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 mixes and the quantity required, so they can adjust their machinery. (4) Material suppliers are notified in real time whether their load has been accepted and will receive appropriate testing results.	*(48, 60)*

3.6. Limitations and Pushbacks 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 STAs are not willing to transition to the technology. Reasons for this include indecision about whether to purchase the system from an outside vendor or create an in-house application, lack of technological skills, and internal/external resistance to the adoption of new technology (Table 5). 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 full extent of the benefits.

Table 5. Limitations of e-Ticketing Systems

Limitations	Source
Static with the mobile geozones, which leads to storage of inaccurate data	*(44, 61)*
Issues with internet accessibility or networks at remote plant locations	*(8, 52)*
Contractors outsource trucks that are not equipped with responders and microchips	*(44, 62)*
Lack of standardized format of data files that are exported and imported into the online database	*(62)*
Difficult decision making related to whether to purchase the system from an outside vendor or create an in-house application	*(24, 63)*
Lack of personnel who are able to adapt to the new technology and nullify the use of legacy systems	*(24, 64)*
Challenges relating to bidding of e-Ticketing providers, including supplemental agreements	*(43)*
Concerns of stakeholders relating to the privacy of stored data	*(48)*
The need for time-consuming and intensive training on multiple e-Ticketing platforms	*(44)*
Stakeholders' concerns about the return on their investment	*(43, 44)*

3.7. 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 adoption rate. The coronavirus created a need for implementing social distancing and minimizing personal face-to-face interactions, and researchers espoused that construction planning and material suppliers should adopt technologies that would accommodate that need *(65-67)*. 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 required to operate safely amid lockdowns and pandemics *(68-70)*. A number of DOTs, including those in the process of developing specifications for e-Ticketing, have also adopted contactless delivery standards to facilitate social distancing (Figure 4). In response to the rising concerns of the pandemic, some e-Ticketing firms, such as Alkon, Earthwave, TruckIT, RuckIT, HualHub Technologies and Libra Systems offered complimentary services and discounts during the pandemic and have realized a significant increase in demand for their products over time.

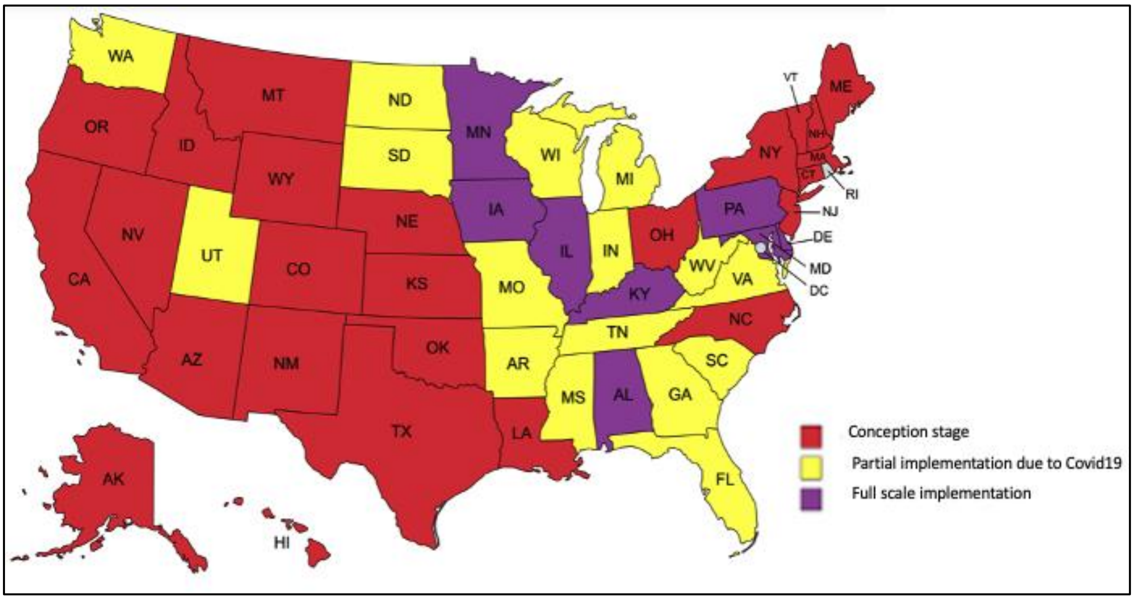

Figure 4. Map depicting adoption of e-Ticketing by states (USA)

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. In 2019, the Transportation Research Board (TRB) conducted a survey and recorded data of ten states' experiences with e-Ticketing. They reported 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 *(41)*. Figure 5 indicates the percentage of states that fully adopted e-Ticketing before the pandemic and the percentage that have partially implemented it due to the rising urgency of the pandemic and the need for social distancing. The coronavirus 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.

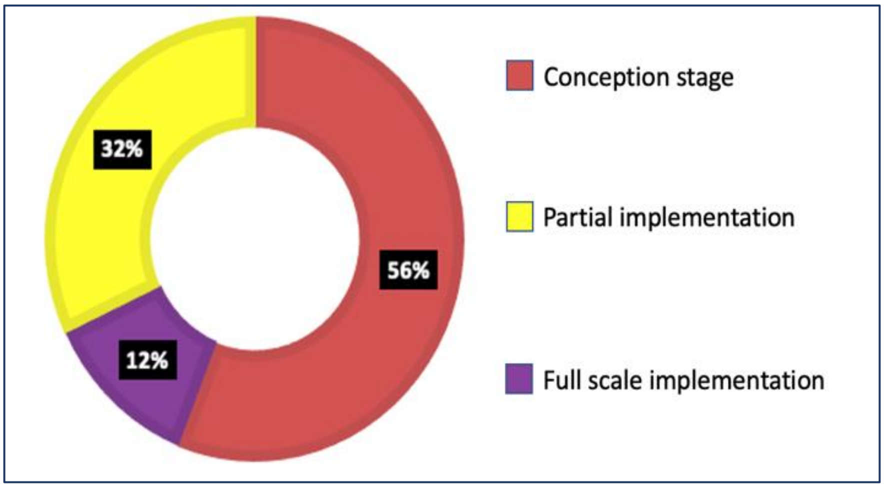

Figure 5. Percentage of states implementing e-Ticketing at various levels

3.8. Indicators for Adoption of e-Ticketing

Multiple studies have emphasized the operational problems and factors related to the deployment of technology that semi-automates or simplifies the daily operations of the construction sector. Ozorhon and Oral stated that the impact of operational constraints should be mitigated through technology implementation and innovation *(71)*. Considered determinants (or indicators/factors) of the propensity to embrace technology are both drivers and obstacles *(72)*, and a company's decision to employ the technology may be influenced by the presence or absence of certain indicators. For new and innovative construction technology to be widely accepted and employed, all stakeholders must have a strong connection *(73-75)*, and to accomplish effective technology integration, it is vital to consider not only technical but also organizational indicators in the review process *(76)*. Technology, organization, and operational difficulties have been shown to have the most impact on whether automation is used *(77)*. The current research categorizes the indicators as follows: (1) ticketing process indicators, (2) technology indicators, and (3) organization indicators. The possible determinants and indicators of e-Ticketing effectiveness readiness (EER) supported by research are summarized in Table 6.

Table 6. 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)															
Automation of ticket details previously entered manually	X	X		X		X	X		X	X		X	X	X	**10**
Automation of documentation of billing and invoices	X	X				X		X	X			X		X	**7**
Increased morale and efficiency of inspectors		X		X	X		X	X	X	X					**7**
Increased ability of inspectors/engineers to handle multiple projects		X	X			X			X			X		X	**6**
Reduction of site hazards	X	X		X	X	X	X		X	X	X	X			**10**
Stakeholders can stay connected in real-time		X		X	X	X			X	X	X		X	X	**9**
Inspectors can collect, review, and document a greater number of 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 waste of materials		X						X			X		X		**4**
One ticket being accounted for multiple times		X							X						**2**
Wrong ticket sent with 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 = (78); b = (64); c = (79); d = (10); e = (16); f = (44); g = (80); h = (81); i = (58); j = (52); k = (21); l = (43); m = (61); n = (82).

3.9. Summary

An electronic or digital format can be effectively used to record and preserve information about materials, such as the quantities that have been produced and the locations from which they originated, and material verification and real-time operational decisions can be made using mobile devices and data that are sent to a server for rapid use by many stakeholders simultaneously. Material data management and integration into information systems for acceptance, payment, and source documentation are made easier using electronic methods. One of the areas where the use of e-Ticketing technology and automation might make a huge difference is asphalt paving. Many studies have been conducted to investigate its numerous advantages, but they have not measured the increased productivity that results from its use, nor have they assessed different stakeholders' (state DOTs, contractors, and material vendors) perception of the technology. Literature on the evolution of e-Ticketing technology in the time of Covid-19 is lacking as well.

4. METHODOLOGY

This research was based on a multiphase strategy that included a structured literature review, semi-structured interviews, and distribution of a survey questionnaire. Figure 6 graphically depicts the research methodology. The existing literature was the basis for developing the semi-structured interview guide and categorization of critical adoption indicators. The results of the semi-structured interview facilitated the development of the survey questionnaire guide.

4.1. Literature Collection Process

A systematic review, an empirical technique that minimizes bias in the identification, selection, and synthesis of a study's outcomes, was used to address the study's research questions. Figure 6 summarizes the four-step process adopted in this study to acquire current and high-quality papers and ensure a comprehensive review of e-Ticketing technology. The steps of the review were: (1) analyze the need for research and develop research questions to guide the study (2) collect data (3) screen relevant articles and review the literature, and (4) identify research gaps and future research opportunities.

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 an e-Ticketing platform. The following four research questions were developed to guide the study and to further analyze the technology in terms of adoption rates, benefits, and limitations.

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 narrower search of journal articles, the authors expanded the search to include book chapters, government reports, conference articles and proceedings, and undergraduate and graduate students' theses and dissertations.

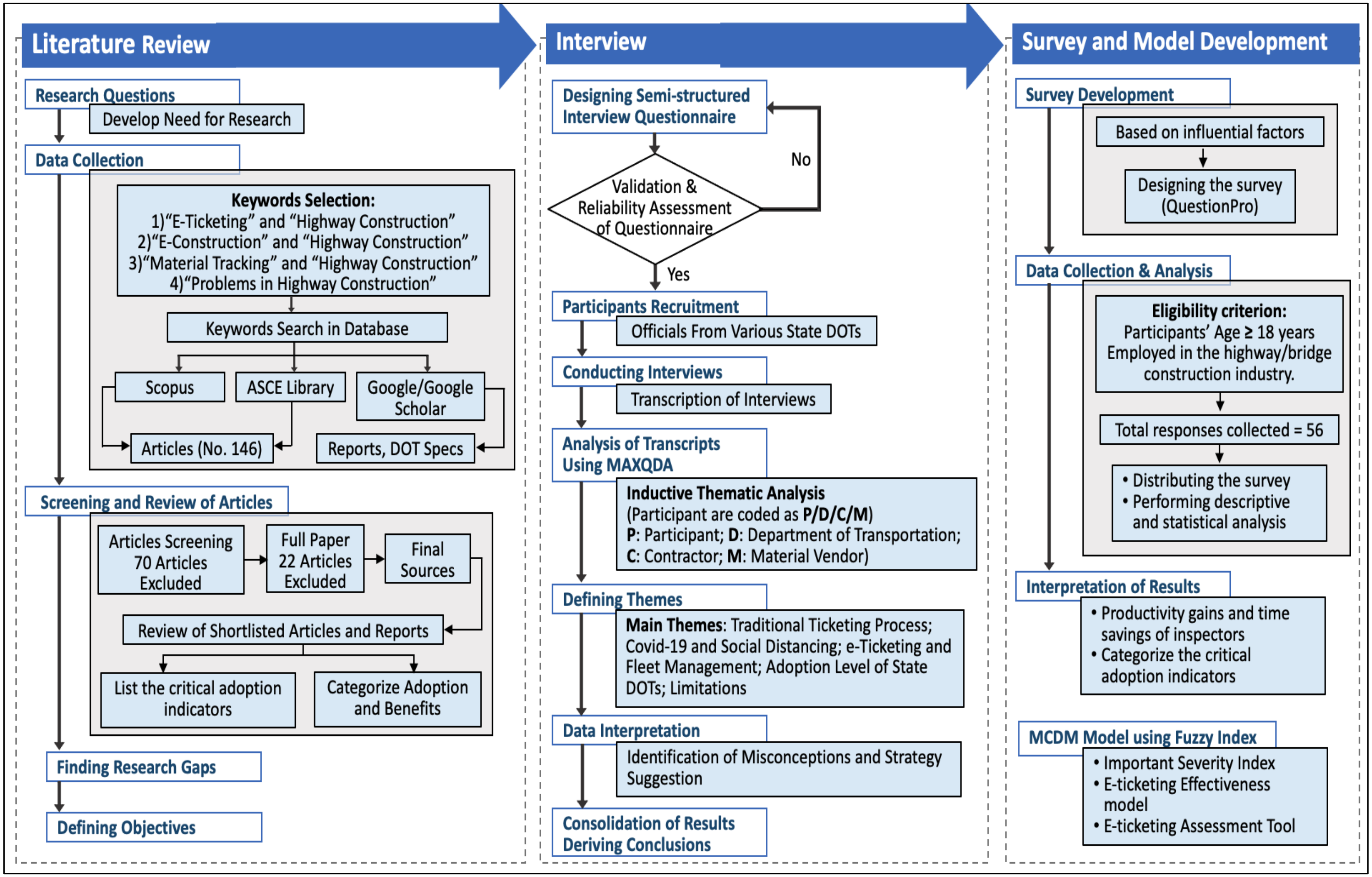

Figure 6. Research framework

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 7 contains a list of the 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 7. Total Type and Number of Sources

Type of Source	Dates	Articles Reviewed	Articles Included
Journals and Books	1990 - 2022	120	37
Conference/Magazines/Theses	2000 - 2022	26	15
Institutional Reports	2010 - 2022	18	13
Total Sources		**164**	**65**

Step 4 – Research gaps, opportunities, and conclusion: We identified the critical research gaps in the literature and related them to the wide-scale implementation of e-Ticketing technology. Based on the research gaps, the authors suggested future research opportunities that would assist DOTs, general contractors, and material vendors nationwide in integrating and reaping the full benefits of the technology. Lastly, the findings and analysis of the study were summarized and interpreted into a single integrated context.

4.2. Semi-structured Interview Methodology

Semi-structured interviews allow researchers to delve deeply into a topic while conversing with the participants in a manner in which clarifying questions may be posed. Thirteen (13) interviews were conducted with people who had been exposed to e-Ticketing technology in some form, as according to proven research, 13 is an appropriate target for qualitative data collection *(83)*. Over a period of 45 to 60 minutes, the interviewees were asked questions from the semi-structured guide. The participants were selected based on their understanding of using mobile devices on construction sites or their involvement in assisting others with technology implementation. The complete framework adopted in the study is shown in Figure 6. The methodology section is further broadly broken down into two groups, data collection and data analysis, which are explained in detail below.

4.2.1 Data Collection

Interviews can be categorized in a variety of ways including structured, semi-structured, and unstructured, but they should address the research questions and goals, the study's purpose, and the research approach used. 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 proceeds and follow-up questions are added, based on the participants' responses. The research team conducted 13 semi-structured interviews with individuals from state DOTs, material vendors, general contractors, and consultants who had knowledge 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, an organization whose purpose is to mandate 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 with different adoption levels of e-Ticketing. The demographics of the participants and their associations are shown in Table 8. Most of the participants had more than 10 years of experience in the highway construction industry; those with less than 5 years of experience were chosen to increase our understanding of the younger generation's perception of technology. The potential participants were invited to participate in the research study through their organization's email addresses. The research team scheduled the 45-to-60 minute sessions and sent the participants URL links. The interviews were conducted virtually through Microsoft Teams by two facilitators who moderated the interview sessions by using a semi-structured guide of questions. The 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). Those who were unable to use the link gave their verbal consent.

Table 8. 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

Planning 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 begins with data collection to investigate phenomena that will produce or construct a theory or explanation *(84)* and entails developing theory from actual fact and progressing from individual observation to the declaration of a general pattern. Its goal is to construct theories rather than test them. In this study, the authors employed the inductive technique by acquiring comprehensive information from participants and organizing it into categories or topics that were turned into theories or generalizations and compared to current research on the subject *(85)*. Figure 7 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). All of the participants' replies to each question were transcribed verbatim and examined for correctness, then were used 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 since this study was concerned with the coding, examination, and patterns found in the recorded data *(86)*. The information's themes were important and related to the specific study issue. This technique was selected because deductive analysis would have involved a pre-existing or framed topic, thus eliminating some of the unknown themes obtained from the 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 participants' responses. The codes were organized by grouping those that were related into a category or topic and isolating the others by putting them 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.

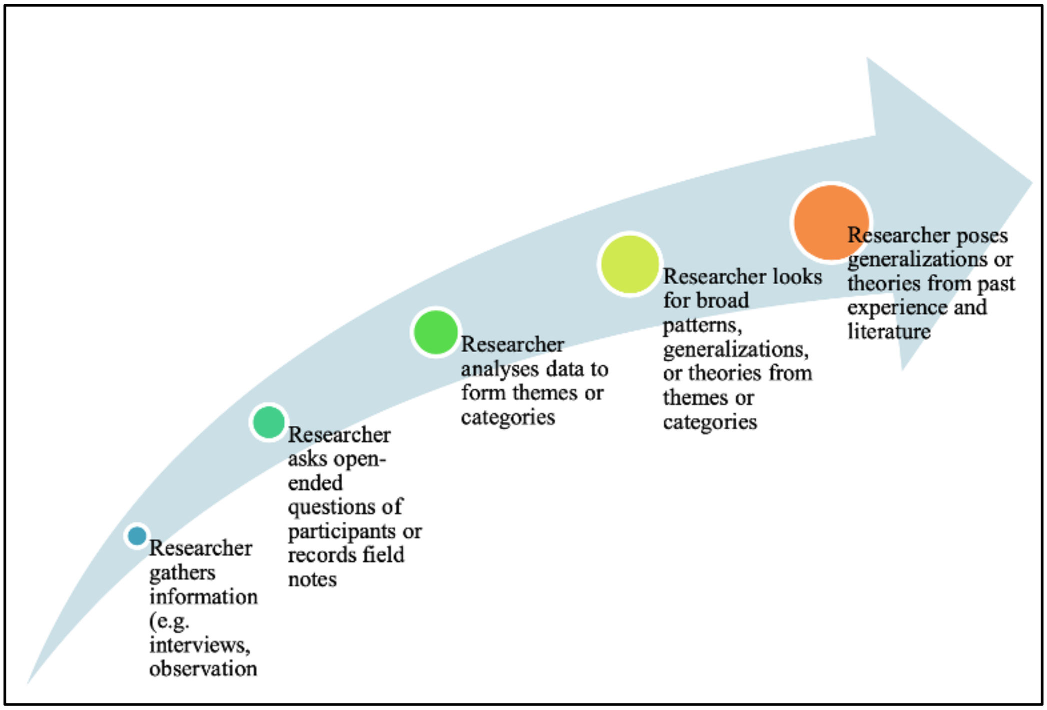

Figure 7. Inductive logic of research study

4.3. Survey Development and Distribution

The research methodology of survey development and distribution consisted of four parts. 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 its implementation. QuestionPro, an online survey platform, was used to construct and distribute the survey to those who had worked on 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.

Survey Sample Questions

10. How frequently has your organization faced the following problems?

	Never	Rarely	Occasionally	Sometimes	Frequently	Usually	All the time
Lost paper tickets	○	○	○	○	○	○	○
Incorrect data entry of tickets	○	○	○	○	○	○	○
Irregularities in the tonnage	○	○	○	○	○	○	○
Maintaining logs of tickets	○	○	○	○	○	○	○

17. Please specify the level of support or opposition (1 - 7) towards the implementation of e-ticketing with listed stakeholders

	Opposition 1	2	3	4	5	6	Support 7
Level of support/opposition from contractors							
Level of support/opposition from material supplying plant/ vendors							
Level of support/opposition from inspectors							
Level of support/opposition from engineers							

How many inspectors would be needed without adoption of e-ticketing technology in this project?

How many inspectors were actually needed in this project after e-ticketing adoption?

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); 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 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. The dataset was categorized into two subsets, based on the positions held by the employees: the first subset 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 the employee's role in the organization.

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

4.4. Steps for Multi-Criteria Decision Making using Fuzzy Index

The survey responses were summarized and ranked using the Relative Importance Index (RII); the Importance Severity Index (ISI) and Fuzzy Synthetic Evaluation (FSE) were used to propose the effectiveness model for e-Ticketing in construction. The Importance Severity Index was obtained to evaluate the relative importance of e-Ticketing effectiveness indicators based on the collected data, but 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, etc.) to classify this information would generate meaningless results, hence non-parametric approaches were used. The current study employed the Importance Severity Index to classify and rank the level of readiness to adopt e-Ticketing. Equation 1 was employed to determine the importance of the index:

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

In the above equation, Likert scale ratings of 1 and 7 were used for i and w_i; i was the point given to each criterion by the responder; w_i was the weight for each point. For all respondents, n was the total number of replies; f_i was the frequency of point i. In this investigation, 'a' carried the most weightage on the likert scale, as its value was calculated as 7. Five important levels were transformed from ISI values: High ($0.8 \leq ISI \leq 1$), High–Medium ($0.6 \leq ISI \leq 0.8$), Medium ($0.4 \leq ISI \leq 0.6$), Medium–Low ($0.2 \leq ISI \leq 0.4$), and Low ($0 \leq ISI \leq 0.2$). With SPSS v.26, the severity index values were derived using Equation 1, based on the survey findings. Based on the magnitude of the importance severity index, one indicator with an ISI value of 0.68 was highlighted as having a "High-Medium" importance level for evaluating e-Ticketing effectiveness in construction. The first three indicators according to their rank (workforce shortage of engineers and inspectors, schedule delays, and cost overruns), are related to organization; the next seven indicators (errors in reconciliation, errors in cumulative tonnage, lost paper tickets, inaccurate ETA of material delivery trucks, excessive waste of material, counting a ticket numerous time, sending the wrong ticket with a load) are related to technology processes; and the last seven indicators are related to technology indicators (automating ticket details rather than entering them manually; automating the documentation of billing and invoices; enhancing the safety of inspectors who collect load paper tickets; enabling project engineers/inspectors/managers to handle multiple projects smoothly and simultaneously with the e-Ticketing systems; preventing or reducing the number of site hazards on road/bridge construction sites with the use of e-Ticketing systems; enabling inspectors, engineers, operators, material vendors, contractors and owners to stay connected via e-Ticketing technology; and increasing the productivity of inspectors and engineers who collect, review, and document tickets.) After ranking the indicators based on ISI, the second step was to run a Fuzzy Synthetic Evaluation according to the following procedure.

1. Develop and establish a set of criteria = $\{i_1, i_2, i_3, i_4 \ldots, i_n\}$, where n is the number of criteria.

2. Develop labels for the set of grade alternatives as $L = \{L_1, L_2, L_3, L_4 \ldots., L_n\}$ and use the 7-point Likert scale.
3. For each e-Ticketing adoption readiness indicator in the survey, set the weighting vector (W_i) as follows:

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

Where W_i 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 (W_i), the MS of a specific indicator ($M_{i)}$, and the summation of the mean ratings ($\sum W_i$).
4. Indicator-specific fuzzy evaluation matrices (R_i) should be constructed

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

where r_{ij} equals the degree to which L_j meets criterion ij.
5. Using the following formula, determine the final FSE results by evaluating W_i and R_i.

$$D = W_i \circ R_i \tag{3}$$

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:
$EEI = \sum_{i=1}^{7} D \times L$

5. ANALYSIS AND FINDINGS

5.1. Descriptive Data Analysis

Of the 53 survey respondents, 39 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 them were from the Indiana and Washington DOTs, although a variety of states at various stages of e-Ticketing adoption were represented. Contractors represented 11% of the participants and 5% were material suppliers. More than 75% visited construction sites on a regular basis; 25% did not. Figure 8 illustrates the various DOT participants who responded to the survey. The survey was circulated to all the stakeholders involved in implementing e-Ticketing, and the survey sample was stratified to better understand the technology's overall implications.

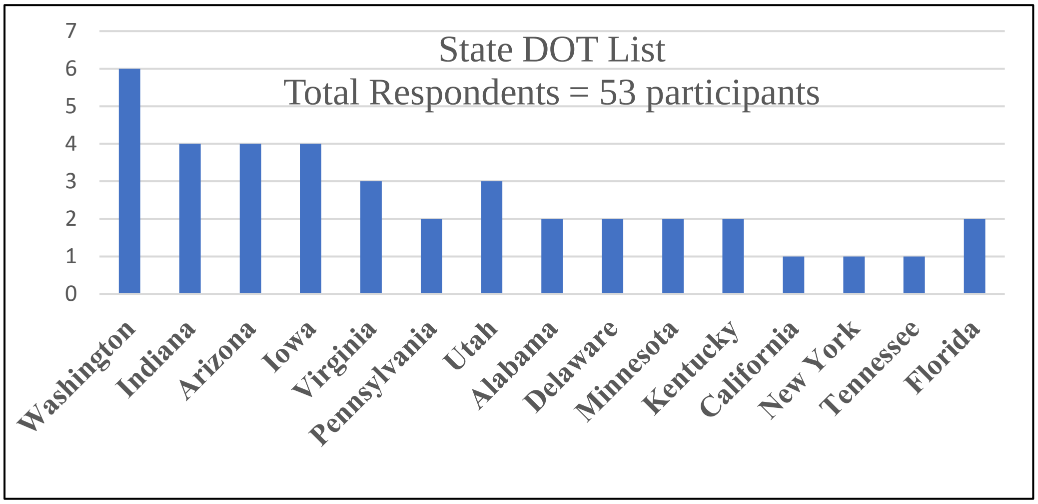

Figure 8. Distribution of DOT participants by state

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. (See Table 9.) This implies that the participants had a great deal of knowledge regarding the construction industry and could be expected to provide credible responses relevant to the research.

Table 9. Years of Experience

	Frequency	Percent	Cumulative%
5 years and less	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
More than 25 years	19	35.8	100.0
Total	**53**	**100.0**	

All of those invited to participate in the survey engaged 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, were responsible for administering the implementation of technology, and had participated in pilot tests or in the implementation process. Project managers, inspectors, and site engineers accounted for approximately 50% of the respondents.

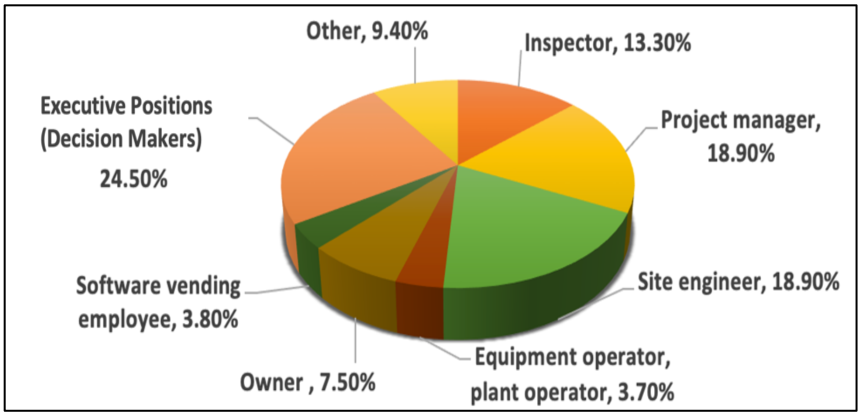

Figure 9. Participants' roles in the organization

5.2. Semi-structured Interviews

This following section consolidates the findings related to the semi-structured interviews; the subsections detail the analysis results of the participants' main concerns and issues about the use of the e-Ticketing platform. The analysis section was guided by 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, and (5) limitations. The following sub-sections broadly explain the interpretations and provide direct quotes by the participants.

5.2.1 *Traditional Ticketing Process (paper tickets)*

The study focuses 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 *(16)*. The semi-structured interview guide contained questions relating to daily operations and the transfer of paper tickets. After careful analysis of the interview transcripts by rigorous coding, grouping, and re-grouping of themes/sub-themes, the research team used the transcribed data to create a flowchart (Figure 10) that depicts the flow of paper tickets from material plants to DOT-owned warehouses and facilitates understanding of the inefficiencies of the traditional form of ticketing. The codes were regrouped to indicate common themes and the repeated themes and sub-themes were deleted, The various directional sub-themes are: (1) manual work, (2) scanning and storing tickets, (3) paper tickets, (4) safety, (5) and documentation staff. It is important to understand the process of traditional ticketing to notice the benefits to the implementation of e-Ticketing software. It was also obvious that state DOTs do not have a common procedure for the management and documentation of paper tickets.

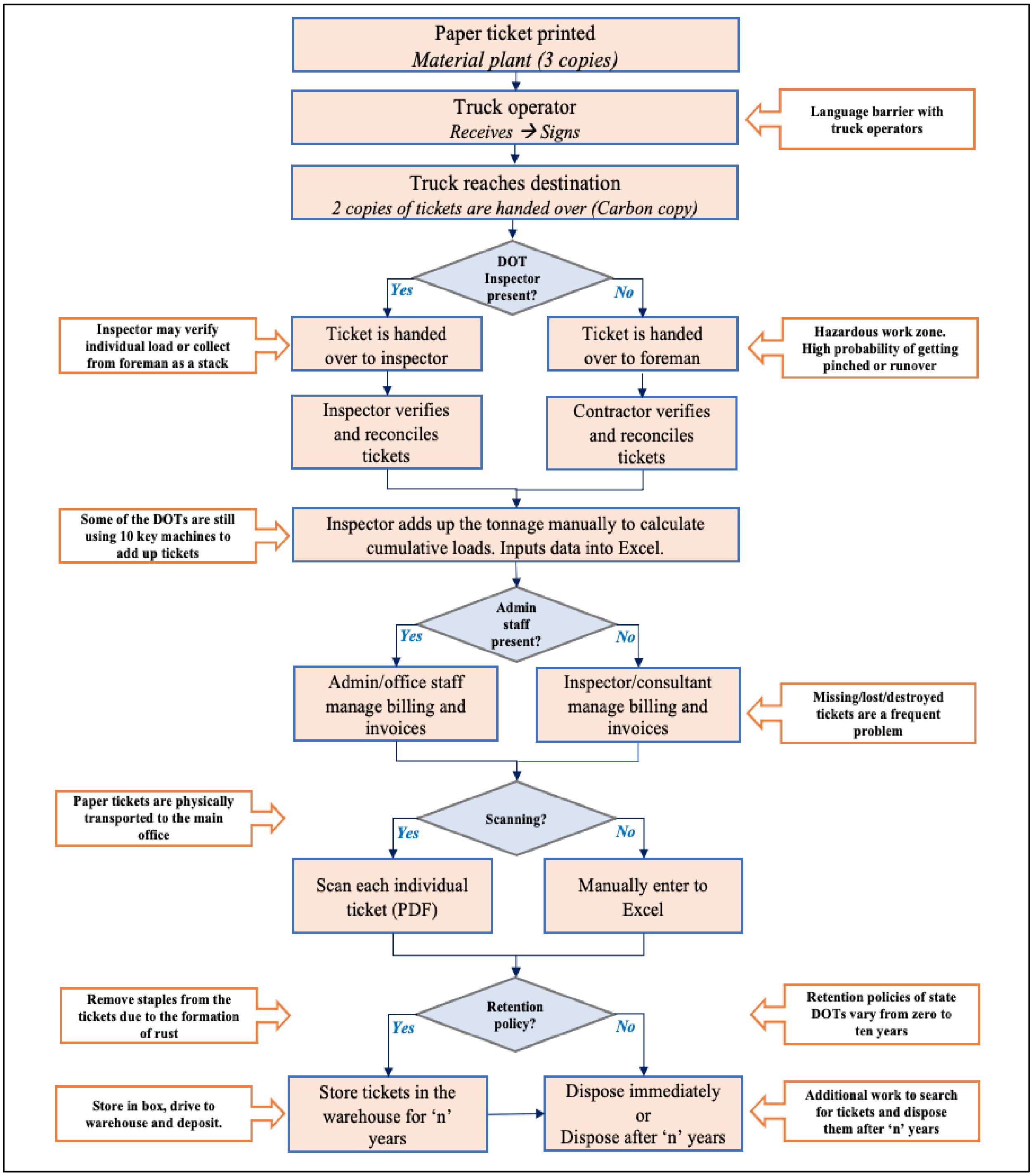

Figure 10. Life cycle of a paper ticket

5.2.1.1. Manual work

The transcripts of the interviews confirmed the inefficiency of paper tickets. It begins at the material plant when the plant operator has to print three copies of the ticket. He rips his copy, and sends two copies to the dump truck operator. The dump truck operator, who is usually from a third-party trucking agency, receives and signs the tickets. This iterative process is time-consuming, and the participants reported a frequent language barrier between the plant operator and the third-party trucking agency's operator. In addition, the dump truck operator often does not send the tube back, which can lead to delays. When the dump truck reaches its destination, one of the contractor's engineers notes the truck number, the time it arrived, and the location of the pour. This data is often used to tally the tickets at the end of the day and ensure that everything is consistent. Before the pour, the inspector 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 tickets and attaches them to a clipboard. 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 tickets to calculate the cumulative loads. Some of the state DOT inspectors are still using 10-key adding machines (Figure 11) on-site to calculate the cumulative tonnage and check the project's progress.

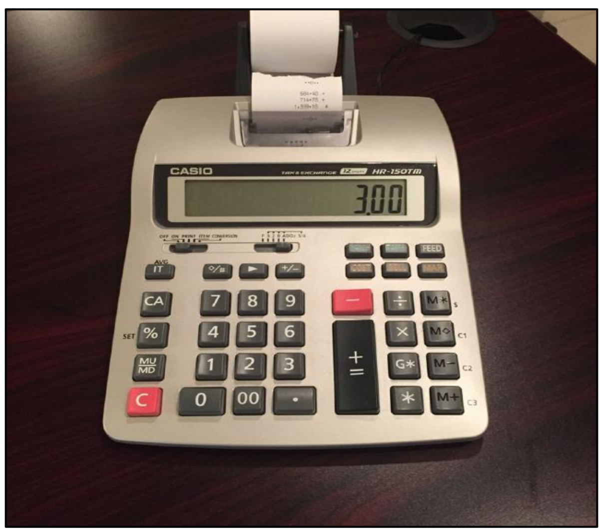

Figure 11. 10-key machines used by inspectors

At the end of the shift, the inspector takes all the paper tickets to the area district office, where the administrative staff sorts and scans them one-by-one into the document management software. Later, the staples are removed from the tickets to prevent rust from forming that would erode the quality of the paper tickets over time. The administrative staff then takes the box of tickets to a warehouse, which is usually away from the district office. Depending upon the retention policy, the administrative staff disposes the tickets stacked in the warehouse after 'n' years. The sub-themes derived and quotes from the participants are depicted in Table 10.

Table 10. 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 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 storehouse."*
	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."*

5.2.1.2. Scanning and Storage of Tickets

The policies, standards, and regulations governing how to maintain and document paper tickets vary drastically from state to state. Most are still scanning each individual paper ticket and retaining it for ‘n’ years in the DOT-owned warehouses. Some are not required to scan each ticket, but manually enter the ticket data into Excel files. A few other states scan all the paper tickets into a PDF format and immediately dispose of the hard copy. 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 11.

Table 11. 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."*

5.2.1.3 Inefficiencies of paper ticketing

In addition to concrete and aggregate, every state produces approximately 3-6 million tons of asphalt each year for highway and infrastructure projects. For medium-sized states such as Indiana, Washington, and Florida, the total number of paper tickets issued and recorded each year by the state DOT ranges from 250,000 to 350,000. All the information in the paper format is "dead," but it has the potential to provide valuable insights into daily operations. Paper tickets are never retrieved unless a project is being audited for discrepancies. Some material plants still use DOT matrix printers with carbon copies, and some of the data on the tickets is barely legible. There are instances where inspectors do not have the paper tickets because they were lost, destroyed by asphalt, torn, or illegible, which leads 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 another cumbersome process. The codes and themes used to understand the inefficiencies of paper tickets are depicted in Table 12.

Table 12. 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."*

5.2.1.4. Safety and hazards

All the participants acknowledged and expressed concern over the collection of paper tickets near dump trucks, as they are in highly hazardous zones, and getting run over or "pinched" by a dump truck is one of the most commonly occurring accidents during this task. Within city limits, highway infrastructures are usually constructed at night since there is more traffic during the day that poses risks to the inspectors and engineers who perform inspections and collect paper tickets. During daytime construction, inspectors work in close proximity to high-speed traffic, with only construction cones separating them from its inherent hazards. The sub-themes derived and quotes from the participants are depicted in Table 13. 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.

Table 13. 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."*

5.2.1.5 Documentation staff

The responsibilities of the DOT administrative staff vary drastically from state to state, as there is not a standard procedure for documenting the paper tickets. The roles of the administrative staff sometimes overlap with the duties of inspectors or consultants. In a few states, it is the responsibility of the consultants or inspectors 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 the paper tickets in a warehouse for as long as the retention policy mandates. The different ways of handling the work and the responsibilities of the documentation process are depicted in Table 14.

Table 14. 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"*

5.2.2. COVID-19 and Social Distancing

When the coronavirus created a need to minimize face-to-face interactions, researchers espoused that construction planning and material suppliers should adopt technologies to bolster social distancing. Many DOTs pilot tested and began implementing an electronic-ticketing system to protect their employees, as the transportation industry is deemed an essential entity that should operate safely amid lockdowns and pandemics. A few DOTs, including those in the process of developing specifications for e-Ticketing, also adopted contactless delivery standards to maintain social distancing. Most state DOTs have partially implemented e-Ticketing, which consists of sending PDF/JPEG versions of tickets to engineers and inspectors to avoid human-to-human interaction. Some of the participants reported that there was an increase in construction activity during the pandemic because of the lack of traffic, and Delaware reported that their state allowed construction projects to move ahead at full speed. There were instances where the paper tickets collected at the site were placed in a plastic bag and disinfected under sunlight for 48 hours and then compared alongside the quantities, and some states mandated vaccinations for their employees which resulted in their losing many of their prime experienced inspectors and engineers. This created an awareness of and a need for standards for implementing e-Ticketing systems. The sub-themes derived and quotes from the participants are depicted in Table 15.

Table 15. 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."*

5.2.3. Fleet Management and e-Ticketing

Fleet management and e-Ticketing are two standalone technologies that have overlapping features and have been pilot tested by various DOTs. The fleet management application deals with truck efficiencies and live tracking of dump trucks with geozones and geofences as soon as they leave the plant. All the pilot tests conducted from 2013 to 2018 included features of fleet management such as GPS responders, geofences, and geolocations. The state DOTs that conducted the pilot tests failed to recognize the return on their investment in the platform, as the initial investment skyrocketed with the use of GPS transponders. This resulted in them rejecting the software, as they had to purchase the technology for the entire state. The sub-themes derived from the interviews and quotes from the participants are depicted in Table 16.

Table 16. 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."*

5.2.4. Adoption Levels of DOTs

This section discusses the extent to which the level of adoption has changed, the implementation strategies that the DOTs 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. A large number of memorandums, letters, specifications, and DOT websites were reviewed to gather information about the levels of adoption. TRB reports that since the beginning of the pandemic, 14 states have begun conducting pilot projects and research, 5 are in the midst of implementation, and 15 have begun working towards e-Ticketing. Because of the coronavirus, more than 32% of the DOTs have implemented specifications that were deployed to general contractors and software vendors to keep their employees safe by maximizing the benefits of social distancing. Memorandums, specifications, reports, and requirements have been issued by a variety of agencies; the degree of acceptance by state DOTs is given in Table 17.

Table 17. Acceptance of Specifications by 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 two vendors
Oregon DOT	Pilot test	No mandate

5.2.5. 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. Adopting integrated technological tools as soon as they become available is the key to unlocking the trucks' potential and monitoring and maintaining the material's quality while it is in transit. The way people live their lives has been fundamentally altered as a direct consequence of developments in technology that have made it possible to perform 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 shown alongside their sub-themes and quotes in Table 18. The traditional paper-ticketing method of processing materials for transportation projects is inefficient and increases project costs and duration. In the midst of the coronavirus outbreak, transitioning to digitization platforms such as e-Ticketing has improved the process in a timely manner.

In every building project, raw materials and equipment account for almost half of the total cost, and the pace at which raw materials and the equipment fleet are used is linked to the project's growth. The effects of e-Ticketing on cost savings are substantial. It reduces the size of the workforce, as fewer people are required to do the same job; engineers responsible for inspectors and/or consultants can supervise projects effectively with ease and accuracy; multiple projects can be monitored simultaneously by engineers who have access to project overviews, allowing them to reassign workforce to areas that need more manpower; and the summary reports generated by the software keep engineers current on the progress/completion rate of the project by merely clicking a button.

The participants mentioned that e-Ticketing saves each inspector approximately 30 to 90 minutes per day, the amount of time-savings is directly proportional to the number of tickets produced on the jobsite, and the increased productivity of inspectors and engineers is directly related to the amount of time saved per day per project. The platform also allows the office/backend workers to assist in inspection duties, as most of their work will be automated and simplified, and will help solve the problem of workforce shortages experienced within the industry. The technology will also increase cross-functional collaboration between all stakeholders, thereby increasing transparency, and will facilitate the transfer of information to all the stakeholders to reduce or eliminate the number of discrepancies and disputes. It will render significant cost savings to the DOTs, as they can reduce the number of consultants they hire and will never have to pay for rejected and partially rejected loads.

Table 17. 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: P12: P8:	*"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."* *"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."* *"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: P7: P3: P11: P8:	*"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."* *"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."* *"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."* *"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."* *"Backend administrative staff can be used to address the problem of workforce shortage as majority of their work will be automated."*

5.2.6. Limitations

The limitations faced by the stakeholders in the implementation process of e-Ticketing technology can be classified into two categories: major limitations and minor hindrances. Major limitations are the key reasons that DOTs have been slow to accept the technology and include internet connectivity, high investment cost, and ROI. Minor hindrances include change management, training of employees, data integrity, and law enforcement. Both the major limitations and minor hindrances are discussed below.

Major Limitation 1: Internet connectivity: Internet connectivity is a concern at many asphalt plants, as those in rural areas have inferior reception and coverage, and some of the projects that encompass different terrains have areas with no access. In remote locations, plants that are seldom utilized may not merit the expense of upgrading them.

⇒ (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."

Major Limitation 2: High Investment and ROI: Since 2013, most pilot projects have used GPS transponders in trucks and have set up geofences and geolocations to track their location in real time.. The inclusion of GPS transponders in every truck drastically increases the investment cost of the technology and incurs liability issues that the state DOTs do not want to deal with. Direct quotes from various state DOT participants who expressed their concern relating to e-Ticketing and GPS transponders are shown below.

⇒ (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."

Minor Hindrances: Implementation standards can overcome the following minor interruptions.
Data integrity - Some state DOTs are concerned about who can access their data and are hesitant to grant permission for depositing electronic tickets into their document management software; many have in-house IT departments who have resisted implementation of the technology.
Employee Training - Inspectors and engineers will have to be trained on multiple software if the state has left it to the contractors to drive the initiative, and that concerns them, as it is often tedious and time consuming.
Law enforcement - In most states, truck operators or haulers need a physical copy of a paper ticket that depicts the material they are hauling to show law enforcement agencies upon request.

When a dump truck is pulled over by the police for any reason, the driver will be asked for the ticket that shows the type of material being hauled.

Change management – Scientific research and analyses show that stakeholders are hesitant to adopt technology because they do not understand its full potential. Most of them feel that there is nothing wrong with the traditional format of paper ticketing, and some are afraid of the technology.

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. When technologies like e-Ticketing are employed, 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. This section discusses the misconceptions in the perceptions of technology and provides strategies to overcome the major limitations addressed in the previous section.

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

All the state DOTs agree that the coronavirus was a catalyst in accelerating the deployment of e-Ticketing. However, states that adopted it without conducting prior pilot projects lacked understanding of the platform's full capabilities, and some restricted themselves to obtaining a photo/PDF version of the paper ticket. Some of the interview participants reported instances in which digital copies of tickets were printed out, signed, and scanned back into the document management software. This was due to the construction manuals stating that all tickets should be signed.

5.2.6.2. Misconception 2 (High Investment)

To understand the level of misconceptions and how it led to delays in the implementation process of e-Ticketing, we need to understand the perspectives of the different types of stakeholders involved in highway construction. From extensive analysis of the transcribed data, it was obvious that stakeholders have different requirements relating to the e-Ticketing platform. None of the state DOTs are interested in having GPS responders so that they can track the live location of each individual dump truck; however, contractors and material vendors have a keen interest in GPS responders and knowing the live location of their fleets. The features of fleet management overlap with the capabilities of the e-Ticketing application, which has resulted in a decade's delay in the implementation of the technology, despite its benefits relating to safety, productivity, and data. Table 19 provides an overview of the features and capabilities of the e-Ticketing platform and its impact on various types of stakeholders. The green checked boxes indicate that the feature is essential to the stakeholder, and the red checked boxes indicate that the feature is of no use to the stakeholders. As is seen in the table, contractors are the only stakeholders who reap the full benefits of the platform. In summary, the coupling of e-Ticketing with fleet management has resulted in a decade's delay of its implementation nationwide.

Table 18. Features of e-Ticketing Essential to Different Types of Stakeholders

Features	State DOT	Contractor	Material Vendor

1. Electronic ticket transfers	✓	✓	✓
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	✓	✓	✗

5.2.7. Strategy 1 – Offline Mode

The lack of internet connectivity is one of the main limitations that has halted the induction of the e-Ticketing platform for 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 of the inspection and material delivery process, and it can be further supported by the inclusion of QR codes or barcodes on the paper ticket or transferring the tickets from the operator's device to the inspector's device, through NFC/Bluetooth. At remote locations with no internet access, plant owners can print paper tickets with a QR code that contains the encrypted ticket data. When the dump truck arrives at the site, the inspector can scan the QR code and note acceptance or rejection of the load and the 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 notations will synchronize. This process will eliminate the need for the paper tickets to be transferred from driver-foreman-inspector-admin staff-warehouse and will facilitate full-scale implementation of the technology.

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

As it is evident from Table 19 and the quotes from the participants, e-Ticketing and fleet management should be separated so that stakeholders can reap the benefits they need without having to pay for what they do not need. Currently, several software vendors who understand this glitch in the implementation process have drifted away from the inclusion of GPS transponders and setting up geolocations in e-Ticketing. If the technology can offer only ticket documentation for state DOTs, it will reduce their investment cost by approximately 90% and should be rigorously pilot tested by all state DOTs. This would be a major step toward achieving a statewide mandate.

5.3. 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 12).

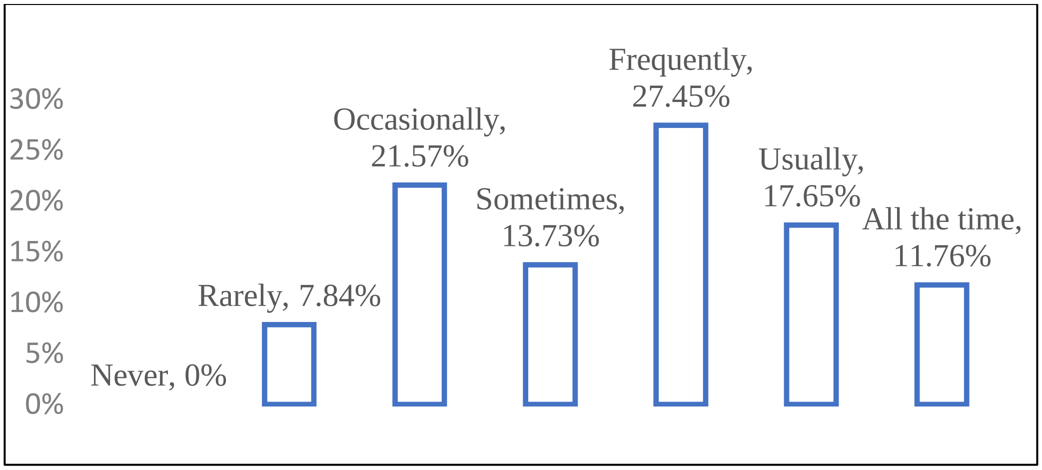

Figure 12. Workforce shortage of inspectors and engineers

5.4. Productivity Gains

One of the questions 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 20. One of the last steps in manual ticketing is processing the invoices for payment. As per the frequency analysis shown in Table 21, this task is 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 common for tickets to be lost or misplaced, which delays the billing process.

Table 19. Time Required for 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 20. Time Required 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, 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 22 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% estimated less than 30 minutes. The dataset shows varied responses, as the amount of time saved by inspectors or engineers differs, based on project cost and duration, and DOTs have different processes for handling material tickets and administrative work.

Table 21. Time e-Ticketing Saves Inspectors per Day

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

5.5. Required Number of Inspectors/Engineers

Table 23 depicts the difference between the number of inspectors required with and without e-Ticketing at project sites that require more than one inspector and shows that paper ticketing requires more inspectors. Two of the responses pertaining to small projects that required only one inspector were not included in the analysis, which showed that e-Ticketing reduces the inspector workforce by approximately 25%. This is 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 22. Percentage of Inspectors Saved by Adoption of e-Ticketing

Criteria	Inspectors required	Mean	Total count
Number of inspectors needed without adoption of e-Ticketing	99	3.09	32
Number of 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%	

Frequency Analysis of Limitations: The bar chart (Figure 13) 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 incurred by the inclusion of 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.

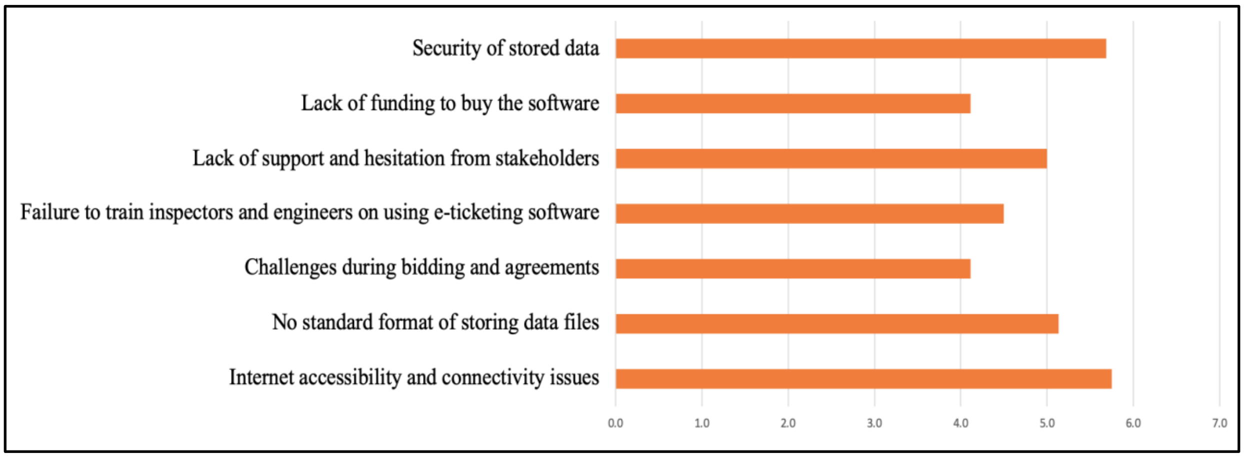

Figure 13. Participants' rating of limitations

The overall mean score of 5.683 for the second major limitation, data integrity, places it between "Somewhat Agree" and "Agree." 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: Group 1, which consisted of state DOT technology implementation administrators in executive positions such as state construction engineer, director, senior state engineer; and 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 24, which denotes the significance of each data group and its limitations.

Table 23. 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. Benefits

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 derived from the literature review were framed into 7-point Likert scale questions, and as shown in Figure 14, the majority of the participants indicated that they either agree or strongly agree with them. Interestingly, a few respondents indicated that they disagree with the benefits of the technology.

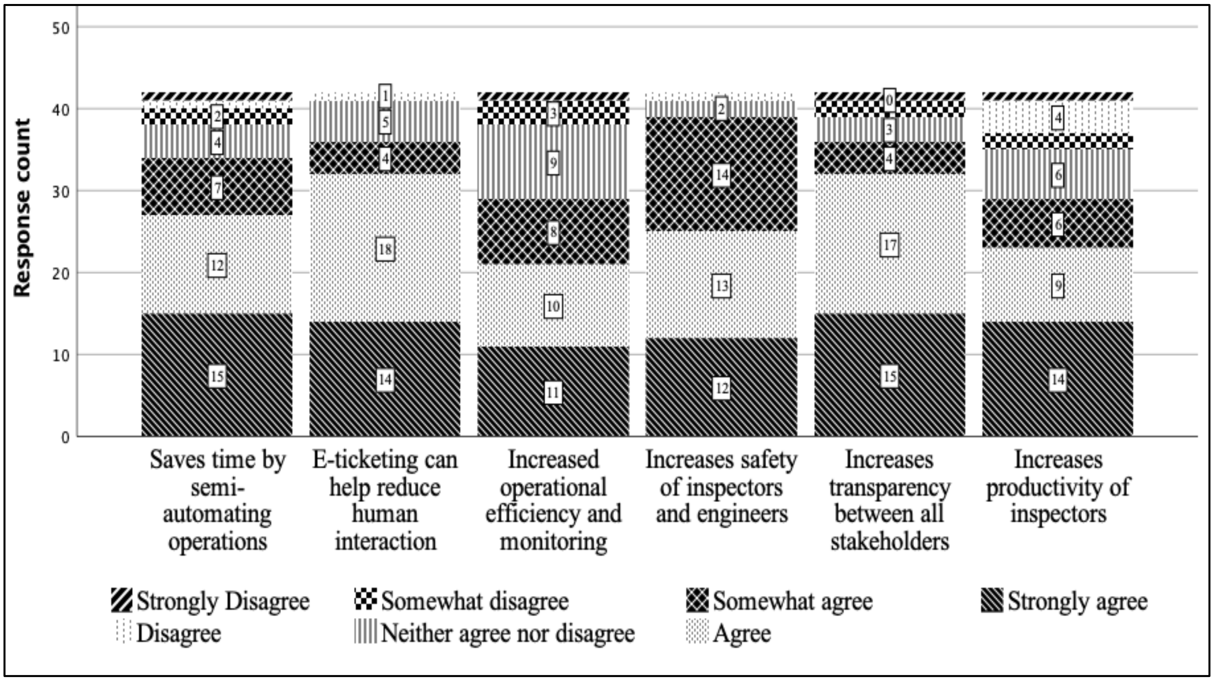

Figure 14. Participants response to benefits of e-Ticketing

The benefits of implementing an e-Ticketing platform were also ranked by the authors, based on the total weighted mean scores from the available Likert scale data, and revealed that they 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 obtain the mean score for each advantage, which was then compared to establish the relative ranking of distinct benefits in descending order of significance. Table 25 depicts the ranking of the benefits and shows that increased transparency, time savings, and increased productivity were ranked highest by the respondents. It is important to note that an increase in the safety of inspectors and engineers was ranked lower than the increase in safety due to social distancing guidelines.

Table 24. Ranking of 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 15 depicts the responses.

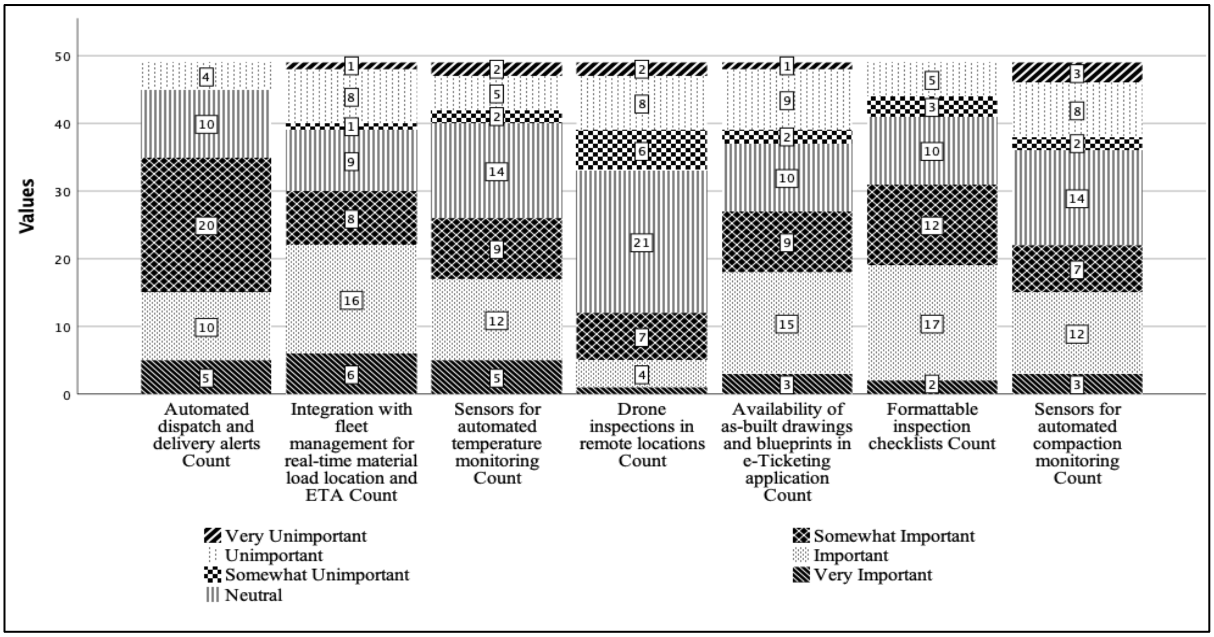

Figure 15. Participants' responses to integrating e-Ticketing with emerging technologies

The responses related to the integration of technologies were varied and indicated that integration of e-Ticketing with fleet management and a formattable inspection checklist was highly important. Responses to the questions about drone inspections were the most neutral, as many of the participants did not have knowledge of the technology's utilization and benefits. The technologies were ranked based on the mean scores obtained from the Likert scale responses, to provide an understanding of the level of significance of the technologies and prioritize the pilot testing of their integration with e-Ticketing.

Table 25. Ranking of Future Integration with 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

5.7. Ranking of Challenges

The study also examined the main problems and issues inherent in the paper-ticketing systems that are a part of day-to-day highway construction operations. The existing literature espoused that since the paper-ticketing system is manual and more labor intensive, it is often subjected to errors in reconciliation, inaccurate records caused by errors in entering data, errors in transmitting tickets, misplacing or losing tickets, recording inaccurate ETAs 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 16 shows the response count of each issue in the respondents' organization.

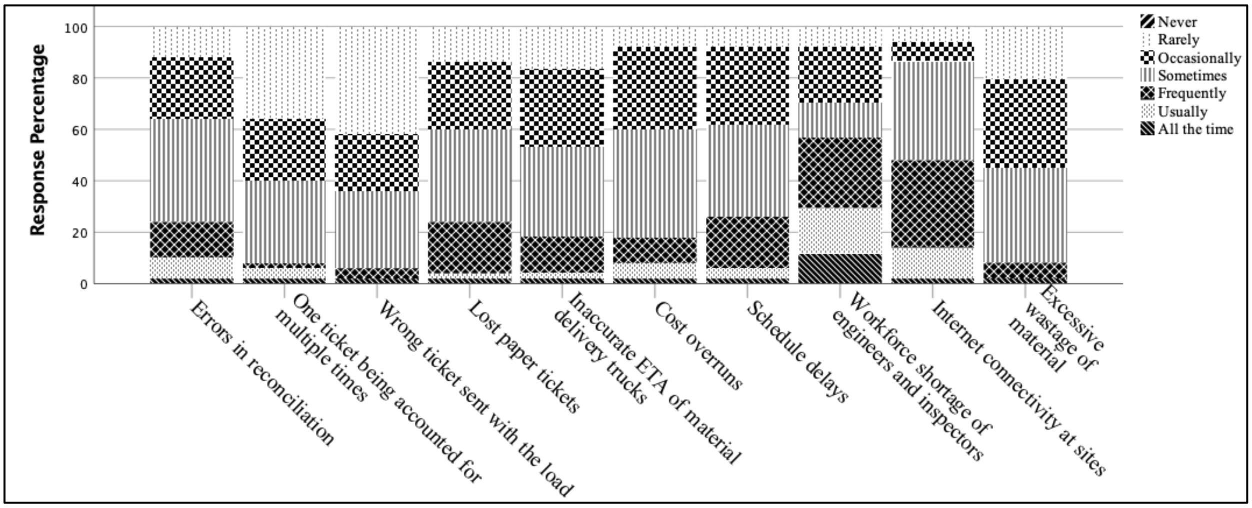

Figure 16. Ranking of challenges by participants

The constraints in highway construction material supply was ranked, using the Relative Importance Index (RII), and on a seven-point Likert scale, problems in highway construction were scored from 1 (never) to 7 (all the time). The formula used to calculate the RII is shown below; the values range between 0 and 1. The significance levels were determined by the following criteria.

$$\text{RII} = \frac{\sum W}{A \times N} \tag{1}$$

In the above equation (1), "W" shows the weight of any variable determined by the participants, "A" represents the highest value of scale (weight), and "N" shows the number of respondents. Table 27 depicts the categories and respective range of the RII.

Table 26. 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 28. Only two challenges for highway construction were identified as having a "High-Medium" relevance level; all others were of

"Medium" importance. The shortage of engineers and inspectors in highway construction was assigned the highest priority, whereas sending the wrong ticket with a load was deemed a minor issue.

Table 27. 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 a load	0.425	10	M

5.8. Quantitative Data Collection and Analysis

The researchers reached out to several state DOTs to collect data relating to individual paper tickets and electronic copies of tickets. The quantitative datasets were obtained from two state DOTs, the Indiana Department of Transportation and the Kansas Department of Transportation. The data and variables obtained were related to the number of e-Tickets, number of inspectors assigned to the project, total cumulative asphalt tonnage, cost of the project, duration of the project, total number of paved miles, and total quantity of rejected material. The collection of these data points aided in grouping and categorizing critical indicators that play a major role in the adoption of e-Ticketing technology. Researchers analyzed the datasets of electronic tickets alongside traditional paper tickets, and the following figures represent the data points obtained from the state DOTs.

Start Date Time	04/25/2022 06:00 AM		**Total # of Loads**	781		Total Contract Bid Cost =		$12,925,658
End Date Time	06/17/2022 06:00 AM		**Total Quantity**	16015.37		Contact Letting Date =		1/12/22
Contract #	R -40496					Contract Completion Date =		7/31/23
Contract Description								
Supplier	Brooks Construction							
Contractor Name	Brooks Construction							
Load #	**Product Description**	**Ticket Number**	**Load Out Time**	**Truck #**	**Net**	**Daily Total**	**DOT Insp**	**Ticket Status**
1	COLD MIX	14526	04/26/2022 06:04 AM EDT	FB40	8.4	8.4		Pending
1	QCQA HMA 3 64 BASE 19.0 MM	1165903	05/11/2022 07:35 AM EDT	S99	19.06	19.06		Pending
2	QCQA HMA 3 64 BASE 19.0 MM	1165904	05/11/2022 07:42 AM EDT	S210	19.91	38.97		Pending
3	QCQA HMA 3 64 BASE 19.0 MM	1165905	05/11/2022 07:46 AM EDT	S288	20.76	59.73		Pending
4	QCQA HMA 3 64 BASE 19.0 MM	1165907	05/11/2022 07:51 AM EDT	S296	22.91	82.64		Pending
5	QCQA HMA 3 64 BASE 19.0 MM	1165908	05/11/2022 08:11 AM EDT	S218	20.26	102.9		Pending
6	QCQA HMA 3 64 BASE 19.0 MM	1165909	05/11/2022 08:29 AM EDT	S248	20.71	123.61		Pending
7	QCQA HMA 3 64 BASE 19.0 MM	1165910	05/11/2022 08:31 AM EDT	S99	19.02	142.63		Pending
8	QCQA HMA 3 64 BASE 19.0 MM	1165912	05/11/2022 08:35 AM EDT	S220	20.75	163.38		Pending
9	QCQA HMA 3 64 BASE 19.0 MM	1165913	05/11/2022 08:37 AM EDT	S210	19.79	183.17		Pending
10	QCQA HMA 3 64 BASE 19.0 MM	1165915	05/11/2022 08:51 AM EDT	S288	20.94	204.11		Pending
11	QCQA HMA 3 64 BASE 19.0 MM	1165917	05/11/2022 08:59 AM EDT	S296	22.52	226.63		Pending
12	QCQA HMA 3 64 BASE 19.0 MM	1165919	05/11/2022 09:04 AM EDT	S218	20.26	246.89		Pending
13	QCQA HMA 3 64 BASE 19.0 MM	1165922	05/11/2022 09:15 AM EDT	S248	19.15	266.04		Pending
14	QCQA HMA 3 64 BASE 19.0 MM	1165923	05/11/2022 09:18 AM EDT	S99	17.35	283.39		Pending
15	QCQA HMA 3 64 BASE 19.0 MM	1165924	05/11/2022 09:22 AM EDT	S220	17.98	301.37		Pending
1	QCQA HMA 3 64 BASE 19.0 MM	1165986	05/12/2022 06:36 AM EDT	S99	19.24	19.24		Pending
2	QCQA HMA 3 64 BASE 19.0 MM	1165988	05/12/2022 06:42 AM EDT	LCK21	19.83	39.07		Pending
3	QCQA HMA 3 64 BASE 19.0 MM	1165989	05/12/2022 06:49 AM EDT	S202	20.53	59.6		Pending
4	QCQA HMA 3 64 BASE 19.0 MM	1165990	05/12/2022 06:53 AM EDT	S288	20.78	80.38		Pending
5	QCQA HMA 3 64 BASE 19.0 MM	1165991	05/12/2022 07:00 AM EDT	LCK25	21.56	101.94		Pending
6	QCQA HMA 3 64 BASE 19.0 MM	1165992	05/12/2022 07:05 AM EDT	LCK23	21.53	123.47		Pending
7	QCQA HMA 3 64 BASE 19.0 MM	1165993	05/12/2022 07:13 AM EDT	LCK26	21.72	145.19		Pending
8	QCQA HMA 3 64 BASE 19.0 MM	1165995	05/12/2022 07:23 AM EDT	BC30	22.57	167.76		Pending
9	QCQA HMA 3 64 BASE 19.0 MM	1165997	05/12/2022 07:29 AM EDT	BC36	20.82	188.58		Pending
10	QCQA HMA 3 64 BASE 19.0 MM	1166000	05/12/2022 07:41 AM EDT	S99	19.09	207.67		Pending

Figure 17. Spreadsheet data of all tickets for a specific project

Raw Ticket Data	
Ticket	1165903
Ticket Status	Pending
Date Printed	May 11, 2022
Time Printed	7:35 AM EDT
Supplier	Brooks Construction
Plant Name	INDOT PLANT #: 3372
Origin Address	-
Contract Number	-
Jobsite ID	R-40496 SR 26
Job Number	40496
Customer Name	BROOKS CONSTRUCTION CO INC
Hauler	STATEWIDE TRUCKING
Truck	S99
Product Description	QCQA HMA 3 64 BASE 19.0 MM
Product	401-07424-19
Product Code	-
Day_Night_Shift	Day
DMF_Num	223372045
Load_Tons_Shipped_To_Date	19.06
Loads_To_Date	1
MgGrossWeight	30.826
MgNetWeight	17.291
MgTareWeight	13.535
ModifiedTkt	0
TransactionID	444317
Load Number	1
Daily Total	19.06
Gross	33.98
Tare	14.92
Net	19.06
Gross 2	67960.00
Tare 2	29840.00
Net 2	38120.00
UOM	Tons
Dispatch #	-
Phase	0061
Phase Description	QC/QA-HMA 3 64 BASE 19.0
Load	1

Figure 18. Raw individual ticket data consisting of all data points

5.8.1. Frequency and Percentage of Indicators

This section displays the frequency and percentage distributions of the responses for all the indicators of e-Ticketing effectiveness that were used to develop an e-Ticketing effectiveness index. The majority of respondents (44.1%) agreed that manually entering ticket details requires a significant amount of effort and should be automated; a much smaller percentage of respondents disagreed with this statement (Figure 19). The majority of respondents (44.1%) agreed that billing and invoice documentation must be automated; a much smaller proportion of respondents disagreed. Most participants (41.2%) strongly agreed that collecting paper tickets for loads is a threat to inspectors' safety; no participants disagreed.

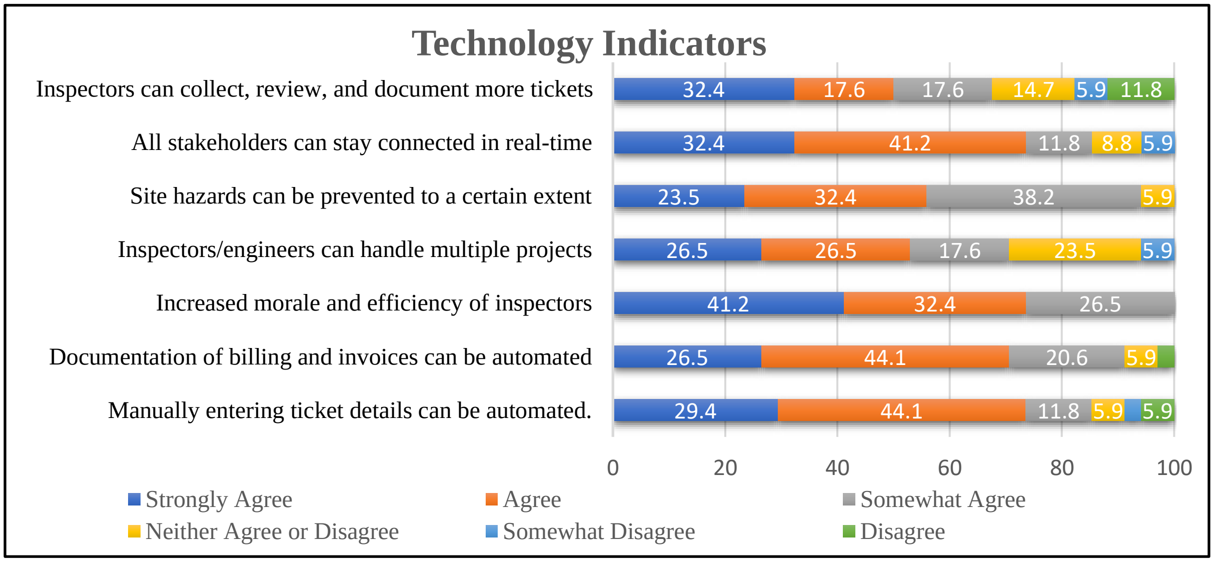

Figure 19. Descriptive data related to technology indicators

According to Figure 20, the majority of respondents (41.2%) said that cost overruns occur occasionally in the construction industry; only 5.9 percent of those polled said it happens frequently. According to their experience, most respondents (35.3%) said that there are occasionally schedule delays in the construction industry; only 29% said that they occur frequently. According to their experience, many respondents (32.4%) said that there is frequently a workforce shortage of engineers and inspectors in the construction industry; only 5.9% said that it occurs infrequently.

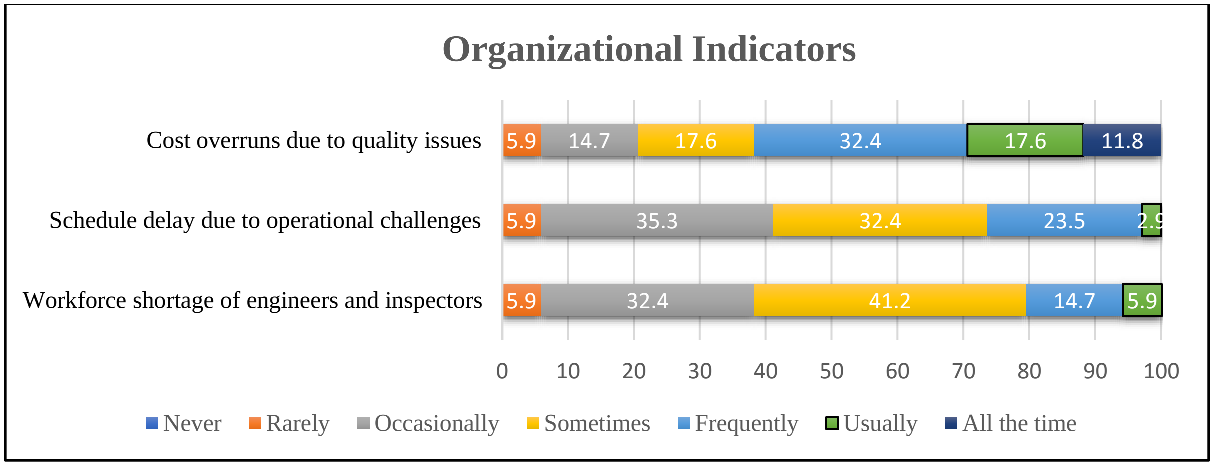

Figure 20. Descriptive data related to organizational indicators

Most respondents indicated that cumulative tonnage errors happen occasionally in the construction industry; 2.9% said that it was a frequent occurrence (Figure 21). A few (8.8%) of the respondents said that reconciliation errors occur 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% said that it is a frequent occurrence. Most (42%) of the respondents had rarely experienced wrong tickets being sent with loads, but 2% said that it occurs frequently. Only 2.9 percent of participants said that paper tickets are often lost frequently, but the majority (41.2%) said that it does occasionally happen.

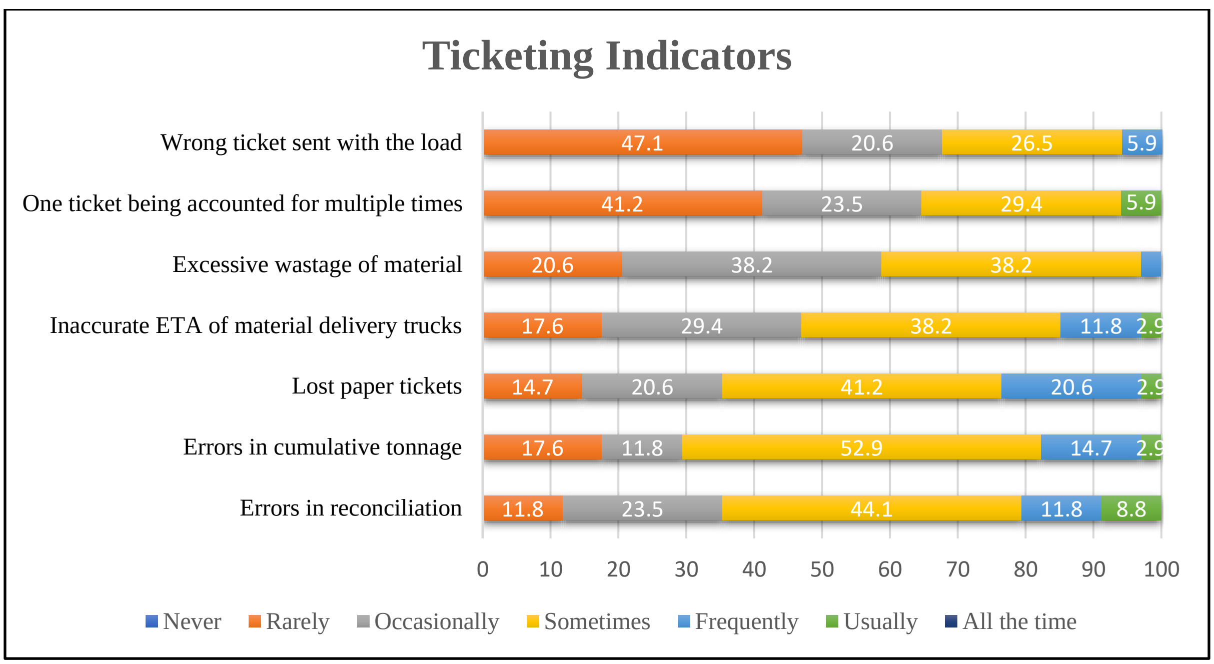

Figure 21. Descriptive data related to ticketing process indicators

5.8.2. Reliability Analysis

The data's reliability was determined prior to running the statistical analyses. 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 measuring a study's reliability and assessing data's quality. The reliability for each construct of e-Ticketing adoption readiness employed in this study was examined (Table 29), and all values were found to be greater than 0.70, thereby verifying the reliability of the survey instrument employed. A coefficient value of at least 0.70 is considered satisfactory. Using the FSE-based model ensured the validity of the data scales used in this research.

Table 28. 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		

5.8.3. Kendall's W test

The Kendall's W test is a crucial step in determining the consistency of responses and was used to verify whether all the participants in the research were in overall agreement. 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 30). At a significance level of 0.05, this finding reveals a high degree of agreement and consistency across survey participants, hence validating the validity and authenticity of the survey responses.

Table 29. Kendall's Test for Concordance

Test Statistics	
Kendall's W[a]	0.355
Chi-Square	193.182
Df	0.16
Asymptotic Significance	0.000
a. Kendall's Coefficient of Concordance	

The data analysis was comprised of multiple steps: identifying the critical effectiveness indicators (CEIs), grouping the CEI (GCEI) for e-Ticketing effectiveness, generating an EEI for each GCEI for e-Ticketing effectiveness, developing the EEI model for e-Ticketing effectiveness, and developing an e-Ticketing effectiveness assessment tool.

5.8.4. Selection of CEIs for Predicting e-Ticketing Effectiveness

Interview participants were asked to rate their agreement with the statements or occurrences of the 17 e-Ticketing adoption readiness indicators on a seven-point Likert scale. The analysis of the mean score, standard deviation, and ranking of the indicators are presented in Table 31. The mean score ranged from 3.04 (incorrect ticket sent with load) to 6.04 (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. The Importance Severity Index was computed to identify the CEIs, and each indicator was assigned the appropriate weighting. Table 31 reveals that the first 11 indicators were considered the CEIs for predicting the effectiveness of e-Ticketing. CEI values greater than 0.50 were classified into three fundamental success predictor groups (ticketing process, organizational, and technology indicators), which were intended to facilitate the FSE (Table 31). The uniformity of the survey respondents was validated using Kendall's W, which determined the group's overall agreement with the mean score and, along with the Importance Severity Index, determined the indicators' significance.

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

Based on Table 32, 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 32). Using Equation (2), the weights of the CEIs and GCEIs were calculated to determine the member composition. The following expressions were used to measure the weights for the ticketing process indicators (W_{CEI1_1}), organizational indicators (W_{CEI2_1}), and technology indicators (W_{CEI3_1}).

$$W_{CEI1_1} = \frac{Mean\ Score\ of\ CEI}{Sum\ of\ Means\ of\ Group\ 1} = \frac{3.74}{24.06} = 0.155 \approx 0.16 \tag{5}$$

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

The degree to which an element is considered part of a fuzzy set, which is sometimes referred to as a membership function (MF), typically ranges from 0 to 1. Therefore, the MFs for CEIs were computed first, followed by the MFs for GCEIs. This is because the MFs were 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 by selecting other grade levels. The following sample expression illustrates the calculations performed for MF for each CEI across all groups. One group is shown below. The MF of all the indicators is shown in Table 33; 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 33. Following the completion of the MF calculation for Level 1, the EEI for each GCEI was determined (Table 33). For example, the EEI for Group 1 (TPI) can be calculated as follows:

$$MFCEI1_1 = \sum_{i=1}^{7} \frac{Proportion\ of\ each\ ranking}{Value\ of\ each\ rank} = \frac{0.00}{1} + \frac{0.18}{2} + \frac{0.12}{3} + \frac{0.53}{4} + \frac{0.15}{5} + \frac{0.03}{6} + \frac{0.00}{7}$$

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

Table 30. 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 a 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 31. 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 a 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 32. 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							

5.8.7. Developing an e-Ticketing Effectiveness Index

To predict the effectiveness of e-Ticketing in the construction industry, a composite EEI was developed by utilizing a linear and additive model. Research on technology benchmarking and the creation of an innovative solutions assessment index were both made possible with the help of the linear model. Previous studies have also utilized additive or linear models to develop indexes. The linear model was standardized to return a sum of 1 or unity in order to generate the composite index (Table 34). Expression of the EEI for construction ticketing processes:

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

Table 33. 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**

The EEI model will provide stakeholders in the highway construction industry with vital information that will guide the automation of work processes, and individuals involved in technology adoption can use the proposed model to assess the readiness of organizations to adopt and implement e-Ticketing technology. The model also can be applied to the process of comparing multiple vendors to determine which offer the most options and features needed. The adoption of the model as a decision support instrument will make it easier for businesses in the highway construction industry to adopt new technologies, thereby reducing the quality problems that are associated with traditional methods.

5.8.8. Grouped Indicators

The results of the analysis yielded ticketing process indicators as the most important category of indicators for determining the level of readiness for implementing e-Ticketing technology. The co-efficient for the group was 0.346 and consisted of 7 indicators. “Errors in cumulative tonnage” was ranked the highest with a mean score of 3.82. The ticketing process indicators 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 on a clipboard for subsequent verification by the inspector, which is an inefficient 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, organizational indicators, had a co-efficient value of 0.328 and was comprised of three indicators: 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 overruns was ranked highest with a mean score of 4.76 ; workforce shortages and schedule delays had identical mean scores 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, as schedule delays in highway construction often lead to cost overruns and are the responsibility of the general contractors, not the state DOTs. Workforce shortages eventually lead to quality issues and ultimately cause cost overruns and schedule delays in highway projects. It is evident from the literature that cost overruns result from material shortages, labor shortages, late delivery of materials and equipment, lack of competent staff, and low productivity.

The third group, the technology indicator, directly relates to the benefits of adopting e-Ticketing technology in highway construction. This group has 7 indicators that correspond to the outcomes of implementing e-Ticketing technology and a co-efficient of 0.326. The ratings of this group were inverted to match with the ratings of occurrences; hence, a low mean score signifies that the participants assigned it a higher importance level. Among the indicators used in the study, “Inspectors can collect, review, and document more tickets” was 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 was 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, can be easily semi-automated, thereby saving a substantial amount of time. Inspectors and engineers can then utilize the time they save to conduct other important activities, such as quality control, which will help improve the performance of highways and alleviate the 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, as they can assign inspectors based on their needs and can remotely monitor the development of several projects.

5.8.9. e-Ticketing Assessment Tool

The e-Ticketing Effectiveness Index can be used by researchers to develop tools and frameworks for e-Ticketing effectiveness in construction, and practitioners can use the outcomes of this study to help them make better decisions, 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. 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. The highest score for the e-Ticketing Adoption Readiness Index is 39.8 and the minimum value is 5.6. If the average score obtained from the practitioners after inputting their values is close to the minimum value, it indicates that adopting e-Ticketing should be a high priority for them. If the score obtained from the participants is close to the maximum score, it indicates that implementing e-Ticketing will be relatively less effective. This study's e-Ticketing adoption readiness index (EARI) and assessment tool can serve as a realistic framework for evaluating an organization's preparedness for automating ticketing and material delivery procedures. Using Equation (7) and Table 35, practitioners can evaluate their preparedness for adopting e-Ticketing technology. The suggested model may also be utilized to offer practitioners a method for comparing two or more e-Ticketing technology aspects being considered for adoption.

Table 34. e-Ticketing Adoption Assessment Tool

Indicators	Participant rating	Group max score	Category coefficient
Ticketing Process Indicators			
Errors in reconciliation	Select rating 1. All the time 2. Usually 3. Frequently 4. Sometimes 5. Occasionally 6. Rarely 7. Never	49	0.346
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			
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		

Indicators	Participant rating	Group max score	Category coefficient
Minimum/Maximum score			5.6 / 39.80
e-Ticketing adoption readiness score			Total score
Percentage to minimum score			Change%

6. CONCLUSIONS

Digitalization has encountered major setbacks in the area of transportation infrastructure projects while most industries, including manufacturing, entertainment, and services, are developing solutions in response to quality, safety, and production concerns and are experiencing significant benefits in the areas of performance and quality. This study aims to increase the overall efficiency of the delivery of highway infrastructure projects through the adoption of e-Ticketing technology, as well as provide avenues for working remotely and automating processes that don't require high levels of skill so that the highway construction industry is prepared to continue operating as an essential business in the face of another global health hazard/pandemic.

Departments of transportation (DOTs) and the private sector invest heavily in printing, delivering, sorting, and archiving paper tickets. The paper-based technique requires a person to collect tickets from truck drivers, record the truck's tonnage and location, compute the yield, and present daily summaries. From the transcripts, it was deduced that e-Ticketing could save from 30 minutes to 120 minutes per day, depending upon the size of the project, which is directly proportional to the number of tickets generated. It would allow state DOTs to assign the personnel who are handling tickets to more significant operations, thereby alleviating 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 three key aspects that will assist stakeholders in transitioning from pilot tests to full-scale implementation. First, to realize the full benefits of the technology, DOTs must purchase the software and mandate statewide use. This can only be achieved by decoupling fleet management (GPS transponders, geofences, and geolocation) from the e-Ticketing application, thereby reducing the cost of the technology by 90%. The DOTs need to have a single source of documentation, with APIs built into the material plant and into the state-owned documentation software. Second, in areas without internet connectivity, QR codes must be used to transfer data from material plants to the on-site inspector's mobile application. This will play a major role in the implementation of the technology, as the paper tickets' handover will stop with the truck operator and will not complete its life cycle. Third, 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 its 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 investigate the other benefits of e-Ticketing and begin pilot programs

This study provided a method for building an e-Ticketing adoption effectiveness model that can assess 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 was utilized. The study found 17 CEIs from the 3 key indicator groups (technological, organizational, and ticketing process). Based on the responses to the 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 understand the degree to which adopting e-Ticketing would benefit their organization. The index and model will serve as an essential starting point for creating 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 determine the stakeholders' perceptions of 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 have been spent manually scanning paper tickets into document management software, matching them up with invoices, paying invoices, and manually calculating cumulative loads. 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 a job site, which is a function of project duration and 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 how to use the systems, and lack of support and hesitation from stakeholders significantly affect the implementation of e-Ticketing technology.

Despite its numerous advantages, this study has the following limitation. The semi-structured interviews and surveys were conducted during the time of Covid-19, and as technology has the potential to reduce human-to-human interaction, most of the participant's perceptions of the technology were influenced by social distancing guidelines and regulations. Some of the participants believed that e-Ticketing is merely transferring photocopies of tickets.

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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?

e-Ticketing Technology Adoption

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	Moderatel y familiar	Very familiar	Extremely familiar
e-Ticketing	❏	❏	❏	❏	❏
Fleet Management	❏	❏	❏	❏	❏

9. How agree are you with the following statements?

	Strongly disagree	Disagre e	Somewh at Disagre e	Neither Agree or Disagre e	Somewh at 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	Occasio nally	Someti mes	Frequen tly	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, accepting, st 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	Disagre e	Somewh at disagree	Neither agree nor disagree	Somewh at 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 Unimpo rtant	Unimpo rtant	Somewh at Unimpo rtant	Neutral	Somewh at Importa nt	Importa nt	Very Importa nt
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. Subcontractors

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