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An assessment of the impacts of electronic ticketing on inspections and material procurement for highway construction

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Introduction: The benefits of incorporating technological advancements and digitalization into construction firms' inspections and material supply procurement operations have been well documented. Despite this and the availability of the technology, however, there is a pervasive lack of understanding in the industry about the appropriate application(s) and benefits for highway construction. This study aims to 1) assess the merits of e-Ticketing technology based on the benefits it provides to the construction industry, and 2) determine the amount of time that it can save inspectors.

Method: A structured survey questionnaire was designed and distributed to a variety of state DOTs to ascertain how they view the benefits of technology, and the advantages cited were ranked according to their importance.

Results and Discussion: The time savings that could be realized by incorporating technology into their operations were estimated by comparing the number of personnel required for inspections before and after implementing e-Ticketing and revealed that 24% of the workforce could be eliminated or reassigned. This study contributes to the existing body of knowledge by providing information about how utilizing technology can help state departments of transportation improve the productivity of their workforce, increase safety and morale, minimize schedule delays, mitigate the prevailing shortage of inspection staff, and prepare for the next pandemic or similar event.

KEYWORDS

e-ticketing, highway, inspection, safety, workforce, material delivery

1 Introduction

Over the last two decades, state departments of transportation (DOTs) have encountered challenges related to inadequate productivity levels and concerns regarding quality. The productivity of workers on highway projects has decreased due to a lack of competent project management personnel and reliance on traditional paper-based management techniques (Taylor and Maloney, 2013). The DOTs' inability to keep up with increasing needs for highway construction and reconstruction projects are at least partly due to a lack of qualified inspectors and insufficient funding, but there may also be quality issues (Oechler et al., 2018; Rouhanizadeh and Kermanshachi, 2020; Safapour et al., 2020; Subramanya and Kermanshachi, 2021). Anderson et al. (2012) stated that although many state DOTs have increased their capacity to retain their employees, they still face a shortage of experienced workers.

Between 2000 and 2010, there was an observed increase in state-owned highway lane miles by an average of 4.1% across the 40 DOTs investigated. However, during the same period, there was a decline of around 10% in the total number of full-time inspectors employed (Taylor and Maloney, 2013). The public sector is experiencing a decline in employment due to various factors such as reduced wages, economic constraints, and a growing private sector. As a result of retirement, proficient and knowledgeable individuals are leaving state agencies and are being succeeded by inexperienced personnel who presume diverse responsibilities at the very beginning of their careers. Several DOT positions remain vacant. The adverse impacts of these hindrances are detrimental to employees of the DOTs. Recent studies revealed that the DOTs in Kentucky and Indiana encountered a deficiency in the number of inspectors as they may have either transitioned to employment in private companies or have retired from their positions within the state DOTs (Xu et al., 2019; Cai et al., 2020; Rush, 2021). The ability to conduct highway inspections has been significantly impacted by the resignation and retirement of highly competent engineers (Li et al., 2019; Newcomer et al., 2019; Subramanya and Kermanshachi, 2021; Nipa et al., 2022). In a bid to resolve this issue, Cai et al. (2020) developed an automated system for inspecting highway projects; however, persistent dependence on paper-based inspection throttled innovation.

Researchers are constantly seeking innovative ways to improve the efficiency of highway construction (Nipa and Kermanshachi, 2022). The Federal Highway Administration (Federal Highway Administration, 2021) conducted research that revealed that incorporating 3D modeling with global positioning system (GPS) sensors could expedite the building of highways while simultaneously improving the inspectors' safety, and some firms who utilized the combination saw their productivity increase by up to 50 % and inspection costs decrease by up to 75 %. The FHWA also promotes electronic construction to reduce project management inefficiencies, record and retrieve information, and boost time management (Patel et al., 2019; Federal Highway Administration, 2020; Embacher, 2021), which could save contractors up to $40,000 annually per project and 1.78 inspection hours per day, and generate 2.75 times as much data (Weisner et al., 2017). PennDOT anticipates annual operating savings of $23.4 million, including a $5.9 million reduction in paperwork (Brinckerhoff, 2017). The Florida DOT simplified its project management, field data collection and organization by using a bespoke software platform, tablets, and formal collaborative partnerships. Electronic construction was utilized for all their contracts to expedite data gathering and address difficulties that emerged during day-to-day field operations, and they revealed that their $1.1 million investment in the technology has resulted in annual administrative processing cost savings of $22 million (Torres et al., 2018).

State DOTs have been pilot testing e-Ticketing since 2015 (Sadasivam and Sturgill, 2021; Tripathi et al., 2022); however, few states have adopted the technology. Numerous researchers have investigated its benefits, but they have not quantified the enhanced efficiency that results from its application. As this is a motivational factor for stakeholders, the purpose of this study is to provide an understanding of the benefits of e-Ticketing and evaluate the improvement in productivity that DOT highway construction engineers and inspectors have realized from its use.

2 Background

Construction projects are increasingly complicated, as more and more data must be captured on a regular basis, and e-construction makes the tasks less time consuming and overall, more efficient than the traditional paper-based approach. It not only saves companies time and manpower, but also allows them to become paperless, gather data more safely, and make it more widely available to users in a timely manner. Several state transportation agencies have held e-construction conferences in recent years to explore the benefits and challenges of embracing e-construction, and virtually everyone reacted positively about the prospects of becoming digital.

2.1 Reduced efficiency in paper ticketing procedure

The primary emphasis of this section is to provide an understanding the constraints imposed by the current ticketing procedure. There are three types of flows in the traditional ticketing system: information flow, material flow, and money flow (Nipa et al., 2019). The contractor places an order with the supplier, the supplier sends the materials to the contractor, the contractor signs for the materials, the supplier bills the contractor, and the contractor pays the supplier. Every step is human-led and paper-based, which is a significant weakness of the current system since it requires too much time and labor (Subramanya and Kermanshachi, 2022), and nearly always carries the risk of human error.

For general contractors and state transportation departments, the current process of manufacturing, organizing, documenting, and storing paper tickets is costly and time consuming. (Kermanshachi et al., 2019; Robertson et al., 2022). During the course of a project, owner's representatives and contractors are frequently required to provide paperwork, which typically involves bills of materials, testing reports, inspection records, and various other informative records, and since most highway construction work is done on the job site, the papers either need to be transferred to computers, which requires the information to be entered again, or remain in a paper format that is cumbersome and difficult to access. The practice of personally collecting truckload delivery tickets puts inspectors in potentially hazardous situations, such as walking alongside moving vehicles and climbing up on trucks. In addition, the likelihood of paper tickets being lost or destroyed means that they are difficult to track, which leads to delays in billing and a significant loss of time and resources (Subramanya et al., 2022a). Entering data manually to transfer information from paper tickets to computers is both time-consuming and resource-intensive and requires multiple points of contact along the way (Nipa and Kermanshachi, 2022). Another problem is that the majority of asphalt plant owners still use carbon-copied dot matrix printers, which makes it hard to read the data.

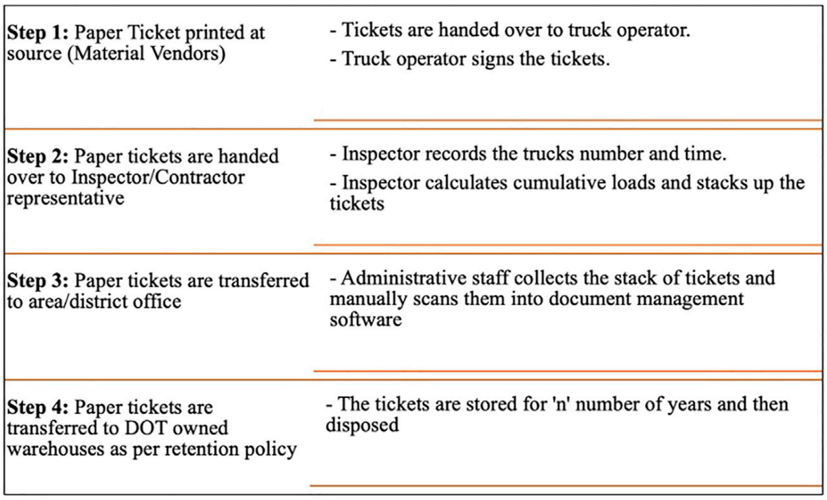

FIGURE 1
Flow of paper ticket from source to destination.

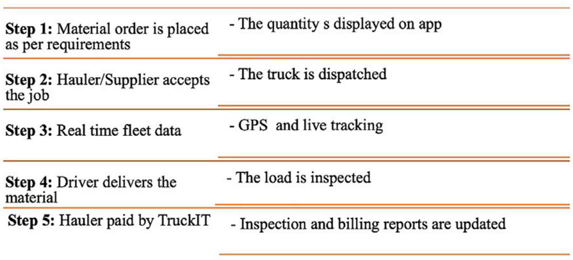

FIGURE 2
Flow of TruckIT material delivery.

Despite recent advances in technology, several DOTs still have their administrative staff manually scan each paper ticket into document management software (Subramanya et al., 2022a), a tedious and time-consuming operation that must be performed repeatedly. Understanding the flow of material tickets from the source (material vendor) to the DOT-owned warehouse is essential to analyze the manual work and cumbersome processes involved in the paper ticketing method. Figure 1 depicts the flow of material tickets from the source to their destination.

2.2 E-construction and E-ticketing in construction sector

The vast quantity of documentation required by the old paper-based method requires a substantial amount of time and effort (Yamaura and Muench, 2018), which is the reason that highway construction companies are considering the advantages of using e-Construction, a paperless system that utilizes an electronic channel to submit, approve, and route data. E-Construction saves money and time, and increases positive interactions between stakeholders (Subramanya and Kermanshachi, 2021). TruckIT is a service provider that exemplifies the implementation of E-ticketing in construction projects. Figure 2 presents the inspection process adopted by TruckIT.

The Michigan DOT investigated the use of e-Construction in a $1 billion project and discovered that it would conserve six million pieces of paper and cut interaction time by 27 days (Brinckerhoff, 2017).

Electronic tickets are digital tickets that can be stored on a mobile device or a computer and transfer physical load tickets over the internet in real time. Since 2015, several state DOTs have conducted pilot programs to investigate the feasibility of transferring material delivery tickets electronically, as it would facilitate efficient monitoring of different varieties and amounts of material mix, as well as the arrival and departure times of trucks (Patel et al., 2019; Subramanya et al., 2022b). Table 1 depicts abreakdown of the several advantages that may be gained by using electronic ticketing.

2.3 Increased productivity with e-ticketing in construction

The FHWA defines e-Ticketing as a software platform that automates the process of information collection and transfer for products being moved from the facility to the work site in real time. It is more effective than a paper-based system as it facilitates daily activities like gathering and interpreting paper tickets, minimizes the workload of highway inspectors, and does not require human intervention for simple tasks (Subramanya et al., 2022b). In addition, it speeds up payment processes, which saves both time, manpower, and other resources that would otherwise be necessary for storing paper, printing, and archiving records. E-Ticketing makes data management more efficient by allowing electronic capture, transmission, and preservation of data; eliminates the possibility of lost or damaged tickets; prevents handovers of paper tickets; and automatically generates, transfers, and stores

TABLE 1 Benefits of e-Ticketing technology implementation.

	Benefits	Category	Studies
1	Ticketing, load calculation, and reconciling process will be partially automated	Time savings	Patel et al. (2019)
2	E-ticketing reduces human contact	Safety	Subramanya et al. (2022b)
3	Area and resident engineers can easily manage several projects	Operational efficiency	Nipa et al. (2019)
4	Prevents dangers and boosts worker morale	Safety	Subramanya and Kermanshachi (2022)
5	All stakeholders can track project progress simultaneously	Transparency	Ogunrinde et al. (2020)
6	Inspectors can evaluate and record more tickets	Increases productivity	Tripathi et al. (2022)

data in a way that is reliable, efficient, and consistent. Electronic data gathering for load deliveries allows safer and more productive inspections, quicker project completion, regular payments, less effort for ticket management, and real-time comparisons between actual and theoretical tonnage (Nipa and Kermanshachi, 2022; Tripathi et al., 2022). Importantly, the likelihood of inspectors being exposed to dangerous working conditions may be greatly reduced, while the likelihood that operating efficiency is enhanced may be greatly increased (Nipa et al., 2019).

2.4 Practical use of E-ticketing in construction projects

The Indiana Department of Transportation (INDOT) uses electronic tickets for its material supply network. Many of their stakeholders use bar codes, and the material suppliers for their projects are required to include the bar code on their tickets. When the transportation firm arrives at the project site, the INDOT inspector retrieves the ticket, using SiteManager software, scans it, and transmits it to all of the stakeholders. According to INDOT project experts, the key benefits include efficient delivery, real-time tracking, and timely billing (Lee and McCullouch, 2007).

The Iowa Department of Transportation suggested implementing e-Ticketing in 2015, using GIS and proprietary software to track supply shipments from their origin to jobsites, and by 2017, they had effectively utilized it to track and synchronize asphalt-bearing vehicles for numerous projects (Schulz, 2017). As a result, other state DOTs are expressing an interest in incorporating e-Ticketing into their programs.

The Alabama Department of Transportation (ALDOT) prioritized the use of electronic tickets after analyzing the pilot experiments being conducted in Iowa. Like many other states, they were challenged by the need to review and supervise a growing number of projects with the same number of employees, and their interest in e-Ticketing stemmed at least in part from their focus on safety and a potential need for an increase in the number of staff. They had recently issued iPads to their field employees, and the time seemed right to give it a try. They have completed numerous pilot projects, and the reaction from all stakeholders has been positive. The first projects were only for asphalt delivery and were conducted with e-Ticketing that operated identically to the issuance of paper tickets.

The Florida Department of Transportation (FDOT) has a great deal of enthusiasm for e-Construction projects, so they undertook a project that they hoped would allow them to transfer all of their design solutions and paper document-related requirements to an electronic format. Numerous paper-to-digital migrations were successfully performed, but in the end, the focus turned to material tickets for asphalt pavement and concrete materials.

The Kentucky Transportation Cabinet (KYTC) employed electronic tickets at an early stage as well. The Division of Construction first heard a presentation on e-Ticketing in Iowa at the Transportation Research Board's Annual Meeting and determined that it would be a successful application in Kentucky, particularly in light of their shortage of inspection personnel. They launched a state planning and research effort at the Kentucky Transportation Center of the University of Kentucky to explore the implementation of several electronic construction technologies, including electronic tickets.

2.5 Challenges of implementing E-ticketing technology

The DOTs are facing challenges in realizing the full potential of e-ticketing technology due to the limitations and obstacles encountered during pilot testing and their ongoing efforts to fully adopt the technology (Subramanya and Kermanshachi, 2022). One of the challenges associated with e-Ticketing is the need to train personnel on novel software and hardware. Additionally, there may be difficulties in assimilating and implementing policy and procedural modifications, as well as securing the support of contractors and subcontractors for new technologies, and initial investment costs (Nipa et al., 2019). Although numerous state DOTs are aware of the benefits, various challenges have impeded their implementation, as reported by Ohio and Iowa DOT in 2016. Including an e-Ticketing platform in the project, requirements pose challenges, as each stakeholder stands to gain distinct benefits from the technology. The findings of another study indicate that inadequate geolocation and geofence configuration can result in inaccurate data retention (Sturgill et al., 2019).

3 Research methodology

The research approach used for this study involved the four steps that are depicted in Figure 3. In the first step, the authors searched a variety of online databases, such as the ASCE Library, Google Scholar, Web of Science, and Scopus, to derive pertinent

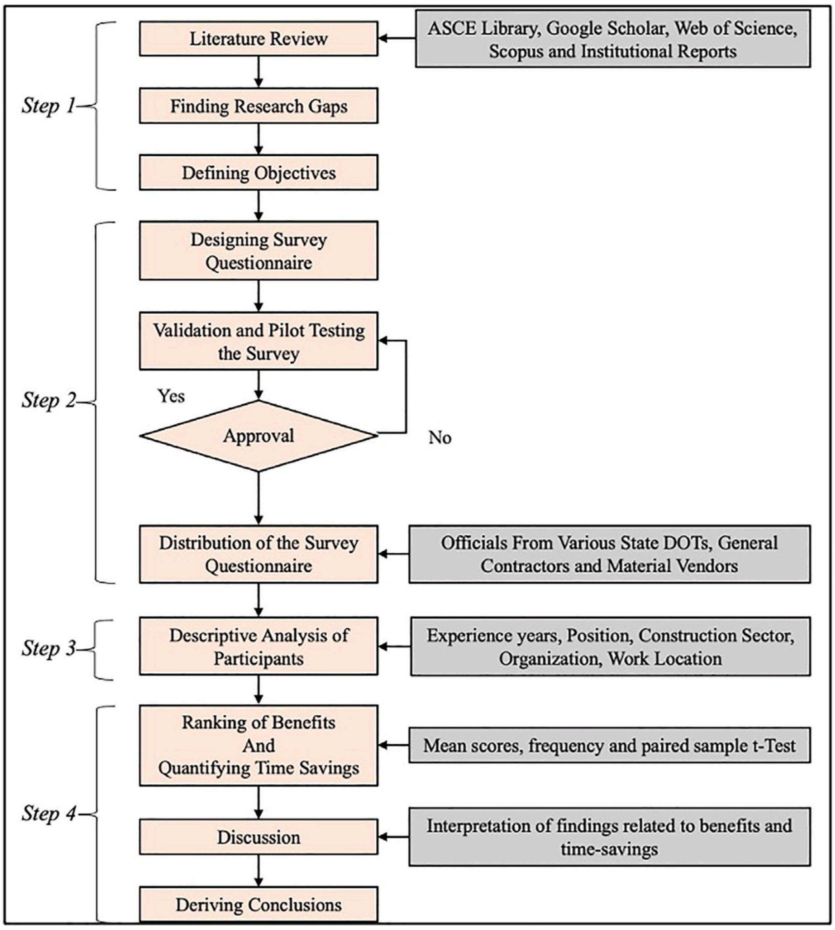

FIGURE 3
Research methodology.

literature on the challenges associated with the utilization of technology, the implementation of e-Ticketing, the delivery of materials in highway construction, shortages in the workforce, and the advantages of integrating e-Ticketing in highway construction.

In the second step, a survey was designed to investigate ways to increase the efficiency of inspection staff via the use of e-Ticketing technology, but prior to it being distributed, a pilot test was conducted ensure that the questions were relevant and succinct. The method employed for participant recruitment was purposive sampling, a technique utilized to identify competent individuals in the highway construction sector who possess specialized knowledge in quality management and technology implementation. This approach was adopted to ensure that the outcomes of the study yield adequate information pertaining to the construction industry. The survey was distributed through an online platform, QuestionPro, to 1,200 individuals who were currently working or had previously worked in the highway construction sector. The potential participants were selected by purpose sampling, which is a method that is used to find professionals in the highway construction industry who have experience in quality management and technology implementation. Three reminders were sent via email, but only 70 individuals participated, which amounted to a response rate of roughly 4.5%. Due to the fact that 17 of the replies were deficient in some way, the authors only considered 53 of them to be legitimate. It should be noted that studies show that fewer responses are received to surveys in the construction sector than in other sectors, due to the demanding schedules.

The demographic profiles of the respondents were analyzed in the third step, and the reliability of the survey instrument was examined in the fourth step.

The following were considered in analyzing the responses: 1) the number of inspectors required under the traditional paper-based system, 2) the number of inspectors required after implementing e-Ticketing, 3) the inspector man-minutes saved by implementing e-Ticketing, and 4) the inspector man-minutes saved for each activity. A paired sample t-test was used to analyze the mean differences in the number of inspectors that were necessary both before and after the introduction of e-Ticketing. The time that inspectors saved on specific tasks on job sites was quantitatively analyzed to understand the average time savings realized per inspector per day by automating unskilled processes.

TABLE 2 Demographics of survey participants.

Demographic variable	Percentage	Demographic variable	Percentage
Experience		State	
Less than 2 years	5.9	Alabama	6.1
2–5 years	2.9	Arkansas	3.0
>5–10 years	14.7	Delaware	3.0
>10–15 years	17.6	Florida	6.1
>15–20 years	8.8	Illinois	3.0
>20–25 years	8.8	Indiana	15.2
Above 25 years	41.2	Iowa	9.1
		Kentucky	6.1
Position		Massachusetts	6.1
Inspector	11.8	Minnesota	6.1
Project manager	8.8	Pennsylvania	12.1
Site engineer	14.7	Utah	6.1
Technology administrator	11.8	Virginia	3.0
Other	52.9	Washington	15.2
Type of Construction Sector[a]		Work Location (Construction site/Office)	
Highway, Roadway	100	Construction site	
Bridges	75	Office	
Water Infrastructure	3		84.8
Industrial Construction	3		15.2
Heavy Construction	36	Type of Daily Material[a]	
Organization		Asphalt	100
State DOT	73.5	Concrete	89.3
Contractor	11.8	Aggregates	96.4
Material supplier	2.9	Recycled Material	53.6
Technology provider/vendor	2.9	Soil	82.1
Consulting firm	2.9	Building Blocks	17.9
Other	5.9	Steel and Rebar	82.1

[a]Note: Type of construction sector and type of daily material supply items were based on multiple responses.

3.1 Survey development and distribution

The questions for the survey were divided into three sections. The first section collected basic demographic information such as how long the participants had worked in the industry, what organizations they had worked for, and the positions that they had held. The second section contained close-ended time-related requestions to gather information about their perceptions of the advantages of using e-Ticketing technology. The third section focused on determining how much an inspection staff could be reduced by implementing an e-Ticketing platform.

Samples of the survey questions are shown below.

i. Please specify the organization you are currently working for.
ii. Please specify your years of experience related to highway construction sector.
iii. Please specify the time required to manually scan a batch of tickets received in a day
iv. Please specify the number of inspectors needed in a project before implementation of e-Ticketing.

3.2 Demographics of survey participants

The demographic profile of the respondents was examined using frequency and percentage analysis. Table 2 shows that approximately 41% of the respondents had more than 25 years of experience, while only 3% had 2–5 years of experience. Approximately 9% of them were project managers, but the majority (around 53%) held a variety of positions. All of them had worked in highway and road construction, and 6% had experience in water infrastructure or industrial construction. The majority of the respondents were employed by a state DOT, but 2.9% of them worked for material suppliers, technology providers/vendors, or consulting/engineering firms. Most of the participants worked in Indiana or Washington (15.2% in each state).

4 Results and findings

The data was cleaned to fulfill all the assumptions of the higher order analysis and was analyzed using SPSS (v26). The subsequent sections present the details of the analysis.

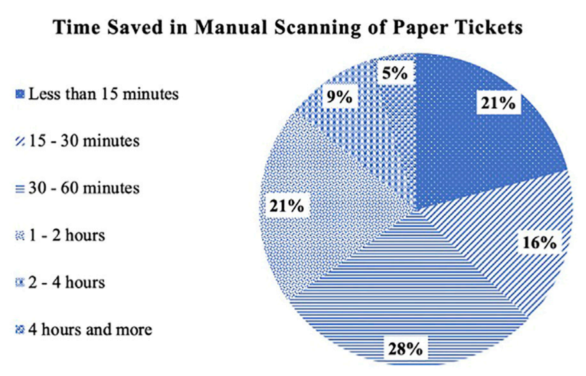

FIGURE 4
Time required by inspectors to manually scan tickets per day.

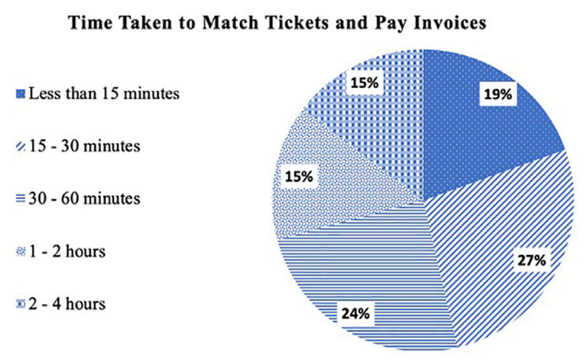

FIGURE 5
Time required to match up tickets and pay invoices.

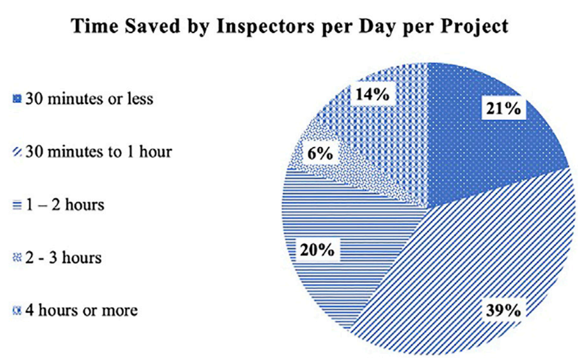

FIGURE 6
Time saved by inspectors per day through e-Ticketing.

4.1 Time-savings of inspectors

The time saving questions in the survey were designed to determine the major benefits of e-Ticketing. Gains in productivity and savings in time were approximated by evaluating the time necessary for each step of paper ticketing. Of the survey participants, 28% claimed that it would take them between 30 and 60 min to physically scan a batch of tickets, 21% responded that it would take them between 1 and 2 h, 16% estimated that it would take them less than 15 min, and a few answered that it might take them 4 h. Figure 4 provides a comprehensive view of the data.

Processing invoices for payment is one of the last phases in manual paper ticketing, and the pie chart presented in Figure 4 shows that the process is time-consuming: 24% of the respondents indicated that it would take between 30 and 60 min to complete this task and 27% responded that it would take between 15 and 30 min (Figure 5). It should also be mentioned that it is not unusual for tickets to be lost or misplaced, which causes a delay in invoicing customers.

Overall, when paired with inadequacies in the paper ticketing procedure noted in the existing literature, these activities took more than 1 h for many responders, making the manual approach exceedingly time intensive. When asked about the amount of time that they thought e-Tickets would save, 39% estimated 30 min to 1 h every day, 20% estimated 1 or 2 h, and 21% estimated less than 30 min (See Figure 6.). The dataset shows a variety of responses since the time saved by inspectors varies with the length and cost of the project. As well, state DOTs have distinct procedures for material handling and managerial duties.

TABLE 3 Reliability analysis of the survey instrument.

Reliability analysis of complete instrument		
	Cronbach's Alpha	N of Items
Benefits	0.714	6
Time savings	0.751	4

Note: A threshold of 0.7 was used to check reliability.

4.2 Reliability analysis

Prior to executing the statistical analysis, the data's reliability was evaluated, using Cronbach's Alpha to measure the amount of agreement between the participants' perception of benefits and actual time savings realized upon adoption of e-Ticketing. The values of both of the e-Ticketing adoption readiness indicators utilized in this investigation (Table 3) were found to be greater than 0.70, which attests to the reliability of the survey instrument. According to Lam and Javed (2015), a coefficient value of at least 0.70 is deemed suitable.

4.3 Benefits of implementing e-ticketing

Implementing e-Ticketing may result in a number of positive outcomes, some of which include increased productivity, time savings resulting from the automation of administrative operations, improved inspector safety, and more efficient operations. Questions were developed on a seven-point Likert scale to address the advantages that were revealed by assessing

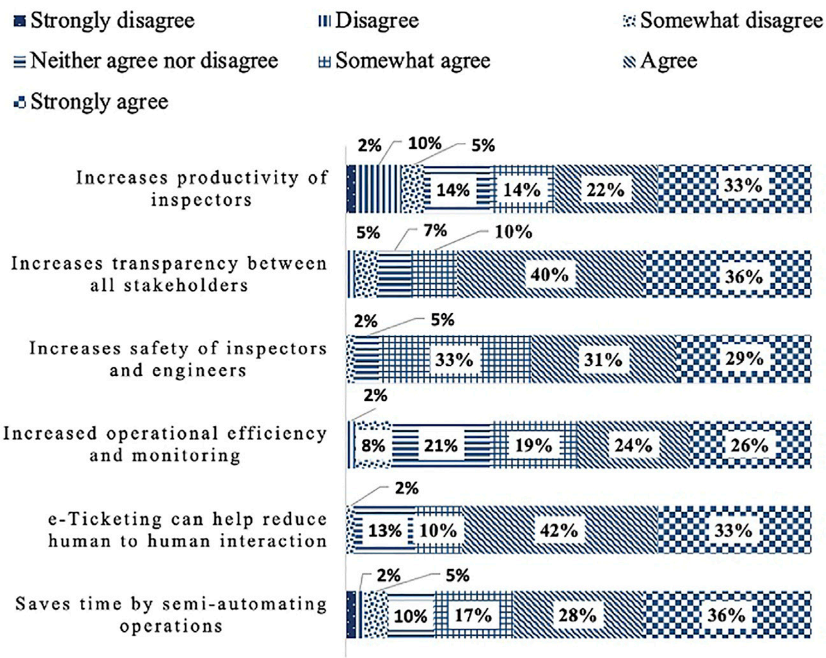

FIGURE 7
Stacked bar chart relating to perceived benefits of e-ticketing implementation.

TABLE 4 Ranking of Benefits of e-Ticketing Implementation.

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

the relevant literature. As illustrated in Figure 7, most of the respondents stated that they either agreed or strongly agreed with the advantages that may be gained from utilizing e-Ticketing technology. Only a few voiced their disagreement with the benefits that the technology provides that might be attributed to their lack of knowledge towards the technology.

The weighted averages of the ordinal scale data were ranked to measure the survey responses pertaining to the advantages of using an e-Ticketing platform, such as time savings, social distancing, operational efficiency, inspector and engineer safety, accountability, and increased efficiency. A seven-point Likert scale was used to determine the average score for each benefit, with one denoting strong disagreement and seven denoting strong agreement. The mean scores were then compared to rank the benefits in descending order of significance, as shown in Table 4. The respondents placed the greatest value on enhanced transparency, and rated time savings and higher productivity as being the other top benefits. Transparency enables managers and team members to comprehend the diverse functions of the entire team, both individually and interdependently, which enhances the team's communication, dedication, and accountability; enables the identification of potential problems; and provides an opportunity to resolve them before they affect a project's outcomes. It is worth noting that the increase in engineers' and inspectors' safety was ranked lower than improvements in safety due to social distancing.

4.4 Paired sample *t*-test

Table 5 shows that fewer inspectors were needed after e-Ticketing was initiated and illustrates the disparity in the number of inspectors needed at a project work site when e-Ticketing is used and when paper tickets are used. Implementing an e-Ticketing platform across the country could potentially lower the number of inspectors needed for highway

TABLE 5 Paired Sample t-Test Variables.

Paired samples statistics				
		Mean	SD	Std. error mean
Pair 1	Inspectors needed without E-ticketing	2.95	1.29	.29513
	Inspectors needed after implementing E-ticketing	2.38	1.39	.31822

Note: Responses that had a single inspector before implementing e-Ticketing were deleted.

TABLE 6 Paired Sample t-Test Statistics.

Paired samples test									
		Mean	SD	Std. error mean	95% confidence interval		t	df	*p*-value
					Lower	Upper			
Pair 1	Inspectors needed before and after implementing e-Ticketing	0.474	0.611	0.140	0.179	0.769	3.375	18	0.003

Note: Responses that had a single inspector before implementing e-Ticketing were removed.

construction projects by 24%, as one inspector, using e-Ticketing, could perform multiple tasks such as recording truck numbers, calculating cumulative loads, scanning individual load tickets, and documenting it all on excel sheets.

The paired sample t-test revealed a statistically significant difference in the mean number of inspectors required on a construction site before implementing e-ticketing (M = 2.95, SD = 1.29) and after implementing e-ticketing (M = 2.38, SD = 1.39); t (18) = 3.375, $p < .05$ (Table 6). The reduction in the number of inspectors is realized as a result of automating multiple manual tasks relating to ticket delivery and inspection activities.

5 Discussion

The overall primary purpose of the survey was to provide an understanding of the perceived advantages of e-Ticketing technology, and the responses revealed that increased transparency and the ability to collaborate across functional lines were considered vitally important. Highway construction projects involve a wide variety of stakeholders, including state DOTs whose employees serve as owners, contractors, subcontractors, suppliers, inspection agencies, and third-party trucking companies, and it is essential that all of the parties involved in a project be linked to one another and receive information at the same time to ensure that there are no communication breakdowns that might result in disagreements and missed deadlines.

Another frequently mentioned advantage was the improved efficiency and time savings that could be realized by implementing e-Ticketing and would benefit all of the stakeholders. Most field-based routine operations, including acquiring paper tickets from operators, computing cumulative loads, documenting vehicle numbers, confirming tonnage, and reconciling tickets, can be performed semi-automatically by e-Ticketing. This would save a substantial amount of time and allow inspectors and engineers to complete other tasks that require more skills, thus easing the constraints initiated by the persistent scarcity of laborers. The enhancement of the overall productivity of inspectors ranked as the third most important advantage.

The COVID-19 pandemic and resulting social distancing protocols made it mandatory to perform tasks with minimal personal interactions, and the use of e-Ticketing technology peaked during this time. Social distancing protocols emphasized the importance of utilizing technology rather than depending upon groups of people to perform a task. This too is a major advantage of e-Ticketing and will prepare companies for future pandemics or similar events.

The respondents to the survey predicted that adopting e-Ticketing technology would save each inspector between 30 and 90 min per day by automating tasks were traditionally performed manually (scanning paper tickets into document management software, matching them with invoices, paying bills, and manually computing cumulative loads). The analysis of the survey responses showed that inspectors' and engineers' productivity is directly proportional to the number of tickets generated on the job site, which is a function of either the time required to complete a project or its overall cost. Therefore, the amount of time that is saved every day per project by adopting e-Ticketing technology is directly proportional to improvement in the overall productivity.

The study also examined whether e-Ticketing could reduce the number of inspectors needed for highway construction projects. Based on the findings shown in Table 4, it was determined that e-Ticketing would eliminate approximately 25% of the workforce for projects that need more than one inspector. Most medium-to-large scale projects that do not utilize e-Ticketing technology require one inspector to collect the paper tickets, document the truck numbers, compute the overall load, and manually enter the information into Excel spreadsheets. This entire repetitious procedure can be automated if e-Ticketing is implemented, and the inspectors can then be available to perform other tasks.

6 Conclusion

Digital technology is used by most industries to expedite business processes, decrease the amount of paperwork, minimize the number of laborers, and reduce overall costs, and the construction industry is beginning to realize the advantages that incorporating new technology could provide. The purpose of this research was to determine the most important benefits of deploying independent technology such as e-Ticketing, and it found that enhanced transparency, greater efficiency, higher productivity, and a smaller workforce are the most important. Other advantages are its ability to semi-automate inspections, collect real-time data, and reduce costs. The adoption of e-Ticketing software is advantageous for all parties involved in a project since it dramatically improves communication, transparency, and operations while also accelerating project delivery.

The widespread implementation of e-Ticketing could be of considerable benefit to businesses that are contending with shrinking labor forces, increased costs, and pushed-back schedules. Lastly, day-to-day operations will be simpler and less time intensive when E-Ticketing takes over the tasks involved in storing vast amounts of information, such as contract values, project durations, actual costs, actual durations, cumulative tonnages, inspection checklist data, types of materials, project size, number of trucks, number of inspectors, etc., that can be used to develop predictive models that optimize costs and ensure quality standards.

Data availability statement

The datasets presented in this article are not readily available because the raw/processed data required to reproduce the above findings cannot be shared at this time due to legal/ethical reasons. Requests to access the datasets should be directed to sharareh.kermanshachi@uta.edu.

Ethics statement

The studies involving human participants were reviewed and approved by Institutional Review Board at University of Texas at Arlington. The patients/participants provided their written informed consent to participate in this study.

Author contributions

The authors confirm contributions to the paper as follows: Study conception and design: KS and SK; data collection: KS, SK, AP, and KL; analysis and interpretation of results: KS, SK, and KL; draft manuscript preparation: KS, SK, AP, and KL; writing, review and editing: KS and AP. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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

Publisher's note

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