Evaluating the Performance of e-Construction Tools in Highway Resurfacing Projects

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Abstract -

Interest in integrating E-construction in highway construction projects has increased in recent years due to reductions in staffing and resources across Departments of Transportation (DOTs) and initiatives from the Federal Highway Administration (FHWA). Specifically, the addition of e-construction methods offers a boost in efficiency and safety in highway resurfacing jobs. E-ticketing, Paver Mounted Thermal Profiling, and Intelligent Compaction were incorporated on resurfacing projects in the state of Kentucky. Using GPS and GIS technology tied with electronic report-out systems, a fleet tracking system traces haul routes, travel times, and tonnage. The addition of paver mounted thermal profilers that allow for remote monitoring of temperatures, and intelligent compaction offers the ability to monitor roller patterns and track the overall compaction effort. The contribution of this manuscript is to document recent advancements, lessons learned, and evaluate their effectiveness compared to traditional inspection practices. Future work discussed include the possibility of combining these technologies into a singular interface for easier integration into the industry.

Keywords –

E-Construction; E-Ticketing; Paver Mounted Thermal Profiling; Intelligent Compaction

1 Introduction

Ground-breaking technological advancements over the past decades have drastically changed individuals' lives. Today, gadgets such as smart phones, personal computers, and tablets are providing a wide range of services in an economical and efficient manner. Industries around the world have made significant changes to adopt to these technologies to improve efficiency and safety, and reduce operating costs. The highway construction industry in the United States has been slower to adopt technology and thus opportunities to improve efficiency and safety in its operations exist. In addition, the industry is facing staffing reductions both in the field and management levels. The labor force is decreasing partially due to a cultural change of young adults wanting higher education and desiring white-collar jobs. Management staffing is seeing a reduction because people are being pulled by the booming private construction industry. Due to the staffing reductions, DOT personnel are being forced to do more work with fewer resources. A study produced by the National Cooperative Highway Research Program (NCHRP) reported that, "DOTs are managing larger roadway systems with fewer in-house staff than they were 10 years ago. For the 40 DOTs that responded to the survey, between 2000 and 2010 state-managed lane-miles increased by an average of 4.10%, whereas the number of full-time equivalents (FTEs) decreased by 9.68% [1]."

The Federal Highway Administration (FHWA) and Departments of Transportation (DOTs) are looking to incorporate e-Construction practices and advanced technologies into their workforce to improve overall efficiency and reduce workload on the personnel. E-Construction is defined as "The creation, review, approval, distribution, and storage of highway construction documents in a paperless environment [2]." These processes can include electronic submission and approval of documents, and real-time management of documents through electronic devices [2]. E-Construction has been heavily promoted by the FHWA through the Every Day Counts (EDC) model that looks to rapidly deploy proven yet underutilized innovations in the highway construction industry [3]. E-Construction was first promoted in EDC-3 in the year 2013, and since then, many DOTs have collaborated to share their e-Construction practices through webinars and peer exchange reports [2]. The addition of e-Construction and other advanced technologies can help maintain high quality and service in highway construction.

One specific area of the industry that can be drastically improved through the addition of technology is asphalt paving inspections. The collection of delivery tickets, monitoring of pavement temperatures, and tracking roller operations all fall under this activity, and is typically done by a DOT inspector. This crucial activity that can impact the long term performance of the pavement is often given little attention due to insufficient staffing levels, and the DOT inspectors having to cover multiple projects at once due to the short paving windows. Incorporating technologies such as e-Ticketing, Paver Mounted Thermal Profiling, and Intelligent Compaction can assist the inspectors improve productivity and document project records.

The three technologies discussed herein have been promoted by many DOTs and were recently tested in two pilot projects by the Kentucky Transportation Cabinet. The goal of this manuscript is to document the results, discuss the lessons learned for industry practitioners, and discuss the possibilities of combining these separate technologies into a singular interface for easier use and integration into the industry.

2 Background

Two resurfacing projects in the state of Kentucky were chosen as pilots to evaluate the effectiveness of the technologies. The study was coordinated with the Kentucky Transportation Cabinet (KYTC) District 7's staff to use the technology complimenting the typical duties of the inspectors. Although a typical highway resurfacing job includes many activities such as traffic control, plant operations, milling, paving, striping etc. For simplicity and a better control of the study, the focus is solely on the paving operations which included ticket handling, tracking mat temperatures, and monitoring roller operations. The data collection during the study included ticket receipt and acceptance; tracking theoretical tonnage; monitoring asphalt temperatures behind the paver, in the screed, and in the hopper; and tracking temperatures at breakdown and roller passes. The data collection was completed both through the traditional manner and through the technologies. The traditional manner included collecting data the way that the inspectors would traditionally. Simultaneously, the same data was collected using the technologies that were being tested during the pilots. The results were then compared for accuracy of the technology data, and the time savings that come with incorporating technology.

2.1 Electronic Ticketing (E-Ticketing)

The process of manually collecting delivery tickets from delivery trucks is an outdated practice that exposes the inspectors to many safety hazards. Whether it is walking adjacent to traffic, climbing the side of the trucks to collect the tickets, or working near moving equipment, the inspectors face many safety challenges while conducting this simple task that can easily be computerized. E-ticketing technology exists that can collect the same information electronically allowing for inspections that are safer and more efficient.

E-Ticketing was promoted by the FHWA in the EDC-4 model as an e-Construction method that can be collaborative and mutually beneficial to both the contractor and the DOT [2]. Additionally, the technology was initially successfully incorporated in highway construction by IowaDOT. In 2015, IowaDOT began the transition to have a completely paperless construction management operation to improve efficiency. The agency used GPS and GIS technologies to trace haul routes, report yield tonnages, and record travel times [4]. In 2016, Iowa achieved a major milestone of 100% paperless processes on a construction project [4]. The implementation of e-Ticketing can be a significant time saver, as it can provide a way for the inspectors to track material deliveries remotely from a safe location.

2.2 Paver Mounted Thermal Profiler

Traditionally, highway construction inspectors have used hand-held infrared thermal cameras/guns to ensure proper pavement temperatures and to identify isolated areas in the mats [5]. Paver mounted thermal profilers provide real time tracking of the temperatures of the entire mat. An infrared temperature monitoring system can be installed on the back of the paver capable of providing a continuous record of mat temperatures throughout the project [5].

This technology has been used by DOTs across the country, and Texas was an early adopter. In 2012, TxDOT implemented Pave-IR as a standard test method into its HMA specifications [6]. The current specification requires the contractor to use a "thermal imaging system" as defined in test procedure Tex-244-F in the Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges [7]. Thermal imaging has also been promoted by the FHWA as a technology to enhance quality control on asphalt pavements [8]. This technology provides a way to track the mat temperatures in real time, on site and remotely, allowing more efficient inspections and the ability to inspect multiple projects concurrently.

2.3 Intelligent Compaction

Intelligent compaction (IC) technology is available to improve quality control during the compaction phase of paving projects. IC rollers are equipped with GPS devices, infrared temperature trackers, accelerometers, and on-board LED screens that display roller movement in real time. These devices track roller movements, temperatures at breakdown, and record the Intelligent Compaction Measurement Values (ICMV) [9]. Currently, two forms of IC rollers are available in the industry. The Original Engineering Manufacture (OEN) is installed directly from roller vendor's factory, whereas the IC retrofit can be installed on select roller models [9].

From 2008 to 2010, 13 DOTs participated in a FHWA, Transportation Pooled Fund (TPF) study that tested and evaluated IC technologies in multiple field pilots [10]. The results of the study showed that IC can be an effective way to track roller passes, and asphalt surface temperatures [10]. Being able to track the roller passes and temperatures can assist the roller operators to improve uniform compaction of the mat. Additionally, the technology enriches projects records for the DOTs to look at if pavement defects are noticed during the life cycle of the road.

3 Methodology

3.1 E-ticketing

E-ticketing technology works during the construction phase of a project to improve project efficiency and safety by going paperless. For the two pilot projects, EarthWave Technologies based out of Indianapolis, IN were contracted to set up an e-Ticketing system. EarthWave provided GPS transponders for all equipment that was to be used during the projects. All transponders could be tracked on EarthWave's online system called FleetWatcher. Additionally, this interface allowed all parties to view delivery tickets electronically, and view cycle times during operations.

A Geo-Fence called a Static GeoZone around the perimeter of the project site and a smaller Geo-Fence around the paver and haul trucks called a Mobile GeoZone were established by the contractor. When the GPS transponders entered or exited the static GeoZone, the system showed that as the trucks entering or leaving the project site, which could be used to control deliveries and reduce wait times in front of the paver. When the GPS transponders entered or exited the mobile GeoZone, the system showed that as the time at which the load was dumped from the truck into the paver.

Each e-ticket would have the same crucial information that is found on traditional tickets such as: Ticket Number, Ticket Data/Time, Material Name, Cumulative Tons, Net Tons, and Dump Coordinates. All e-Tickets for the project could be accessed on the FleetWatcher website, and in the field through the FleetWatcher app.

Throughout the projects, the traditional tickets were collected by the inspectors, and the ticket information was recorded in the field along with the time it took to retrieve the individual tickets. The same information was then retrieved from FleetWatcher, and the time required for this activity was also recorded. The conventional and the technology information was then compared for data accuracy and time savings.

In addition to measuring the accuracy of the data and time savings, electronic tickets can be used to calculate theoretical tonnages in a more efficient and safe manner. The theoretical tonnage is a crucial calculation that the inspectors perform to estimate the amount of asphalt mix that should be used over a certain paved distance. This value is then compared to the cumulative tons given on the delivery tickets to confirm if the crews are paving according to the specifications, and to ensure that material is not being wasted along the process. The theoretical tonnage calculation is given be Equation 1:

$$\begin{gathered} Theoretical\ Tonnage(tons) = \\ Mix\ Density\left(\frac{lb.}{sy.in.}\right) \times \\ Pavement\ Thickness(in.) \times \frac{1(sy.)}{9\,(sf.)} \times \\ Pavement\ Width(ft.) \times \\ Pavement\ Length\ (ft.) * \frac{1\,(ton)}{2000(lb.)} \end{gathered} \tag{1}$$

In Equation 1, the pavement length is calculated from the dump coordinates on the e-Tickets. To calculate the theoretical tonnage, the distance between a dump location and the starting point, or between two dump locations is estimated using the "measure" tool in Google Earth. This distance is then used in Equation 1, along with the other factors which are found in the specifications to estimate the yield tons for the paved surface. This value can then be compared to the cumulative tons delivered to track project productivity.

3.2 Pave-IR

As mentioned previously, the Pave-IR system provides real time temperature tracking of the entire mat. For the pilots, MOBA Automation installed thermal cameras on the back of the pavers to track the mat temperatures at placement. Unfortunately, due to communication issues between the contractor and the technology vendor, no cameras were placed over the hopper, or the screed to track the temperatures of the dumped load. The installed infrared cameras displayed the mat temperatures in real time on LED screens mounted on the pavers for the crews to look for cold spots and take immediate measures if necessary. Additionally, the thermal recordings of the mat are directly uploaded to a MOBA Cloud, or they are stored on a USB storage drive for remote areas without sufficient cellular signals.

For the study, the mat temperatures at various locations were recorded using a temperature gun periodically throughout the projects. Following project completion, the same thermal recordings were retrieved from the MOBA Cloud, and the manually recorded temperatures were compared to the Pave-IR temperatures to assess the accuracy of the data. This technology allows the inspectors to monitor and inspect paving projects remotely and cover multiple projects at the same time in an efficient manner. Additionally, this allows the DOTs to review pavement temperatures at a later date if failures are noticed on the road.

3.3 Intelligent Compaction

Prior to the pilot projects, Sitech Solutions were contracted to setup an Intelligent Compaction system for the study. Two breakdown rollers were retrofitted with the Intelligent Compaction technology that could track roller movements, temperatures at breakdowns, and record the ICMV. A LED screen mounted on the roller shows real time tracking of roller passes which can assist the roller operator achieve uniform compaction of the entire mat.

During the pilots, the roller movement and the temperatures at breakdown were tracked periodically by the inspector to ensure proper compaction. The IC system on the roller, recorded the same information electronically and displayed it on Sitech's web-interface called VisionLink. This system displays information such as, temperatures, roller passes, and ICMV on a GIS-based map. Following project completion, manual data and IC data was compared for accuracy. IC provides similar benefits to Pave-IR in that it allows the inspectors to cover multiple projects at once, and it provides continuous project record to review if a failure is noticed in the pavement.

4 Results

4.1 E-ticketing

When comparing the accuracy of the data collected electronically by FleetWatcher to the traditional tickets, it was found that the data aligned perfectly for following categories: Truck Number, Mix Design, Ticket Number, Net Tons, and Cumulative Tons. A small sample of the collected data is shown in Table 1 where the "conventional" data was gathered from physical tickets, and the "technology" data was recorded through FleetWatcher. Although Table 1 shows a small sample of data collected during a single shift of one project, it is representative for all 75 load delivery tickets.

Improving inspector safety was one of the main driving factors behind conducting this study. As mentioned earlier, highway construction inspectors face many hazards while collecting delivery tickets. Activities such as walking adjacent to traffic, climbing the side of dump trucks, and working next to heavy equipment exposes the inspectors to unnecessary risks. The data from the projects shows that the time to acquire the traditional tickets was significantly longer than through FleetWatcher. Additionally, data retrieval through e-ticketing could be done in a safe environment away from the hazards. During this shift, a total of 19 tickets were collected from delivery trucks. It took the inspector approximately 54 minutes to collect the 19 paper tickets. In comparison, the same data was retrieved from FleetWatcher in just 18 minutes. Additionally, the data from FleetWatcher was retrieved in the inspector's truck, which eliminated the hazards from physically collecting paper tickets.

E-Ticketing provides a way to calculate theoretical tonnages in a more safe and efficient manner. It is important to note that the calculated theoretical tons rarely match with the cumulative tons delivered to the project site due to the many errors and uncertainties that are present in construction projects. However, huge differences between the values can indicate that the pavement is too thin, too thick, or material loss along the process. Several theoretical tonnage calculations were performed using the dump coordinates recorded by FleetWatcher, and the information given in the specifications. Table 2 shows the results of the calculations. Many accurate estimations were calculated throughout the study, and the KYTC inspectors assigned to the projects confirmed that the theoretical tonnages calculated followed the trends noticed in the field.

To further investigate differences, a theoretical tonnage was calculated for each load delivery and compared to the values on the ticket. With the

Table 1. Data Alignment, Date: 07/05/2018

Data	Truck Number	Mix Design	Ticket Number	Net Tons	Cumulative Tons
Conventional	CB25	CL4.S.38 A 76	868794	25.72	51.30
Technology	CB25	CL4.S.38 A 76	868794	25.72	51.30
Conventional	PR10	CL4.S.38 A 76	868807	26.06	103.48
Technology	PR10	CL4.S.38 A 76	868807	26.06	103.48
Conventional	H98	CL4.S.38 A 76	868811	25.30	155.13
Technology	H98	CL4.S.38 A 76	868811	25.30	155.13

Table 2. Theoretical Tonnage

Date	Approx. Dist. (ft.)	Lane Width (ft.)	Thickness (in.)	Density (lb./Sy.In.)	Theoretical Tons	Cumulative Tons
7/2/2018	3205.49	14	1.25	110	342.81	381.60
7/3/2018	3219.49	14	1.25	110	344.31	358.88
7/6/2018	7634.74	14	1.25	110	816.49	801.26
7/7/2018	6954.59	14	1.25	110	743.79	754.44

Table 3. Paired Samples T-Test

Pair	Mean	Std. Deviation	Std. Error Mean	t	df	p(2-tailed)
Theoretical - Actual	-0.710	20.810	2.403	-.296	74	0.768

corresponding nature of the data, a paired samples t-test will unveil whether there are any statistical differences between the theoretical and actual ticket loads. The results of the paired samples t-test are reported in Table 3. The null hypothesis of a paired samples t-test is that the true mean difference is zero with the alternative hypothesis being that the true mean differences are not zero. The high p-value of 0.768 indicates that the null hypothesis cannot be rejected and that the true mean difference is zero. Practically speaking, there is no significant difference between the theoretical and actual ticket tonnage. Thus, while differences are expected from a variety of error sources, the theoretical tonnage calculation embedded in the e-ticketing software is effective at reporting accurate quantities for these projects.

4.2 Pave-IR

Utilizing Pave-IR proved to be an effective way of tracking pavement temperatures throughout the projects. During the paving operations, it was noticed that the real time display of mat temperatures on the LED screens allowed the crews to quickly patch any cold spots that were noticed. Concerning data accuracy, it was found that the temperatures that were physically collected during the operations using an infrared gun were well aligned with the temperatures recorded using Pave-IR. Figure 1 is a screen shot of the Pave-IR interface that shows a continuous recording of mat temperatures throughout the paving operations. Table 4 provides the field recorded temperatures and the Pave-IR temperatures, and it can be seen that the percent differences between the two methods are almost insignificant. Although the Pave-IR data shown here is a small sample, it is representative of the data collected across the two pilots for the study.

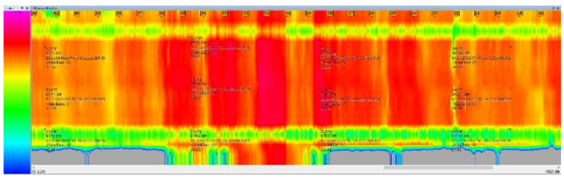

Figure 1. Pave-IR Interface

In addition to data accuracy, retrieving data from Pave-IR was much more efficient and eliminated the need for the inspector to be physically present at the project site. Project records were improved through Pave-IR as well since it provided an electronic cloud storage of the data in comparison to the traditional method where the temperatures were written down in inspector notes.

4.3 Intelligent Compaction

Of the three technologies tested during the study, Intelligent Compaction was the least successful in terms of data accuracy and improving project efficiency. Poor

Table 4. Temperature Alignment, Date: 07/02/2018

Data	Lat.	Long.	Avg. Mat Temp (◦F)	Percent Difference (%)
Conventional	38.403	-84.567	297.33	0.78
Technology	38.403	-84.566	299.67	
Conventional	38.0417	-84.567	290.00	1.78
Technology	38.042	-84.567	295.27	
Conventional	38.0396	-84.570	293.00	1.12
Technology	38.04	-84.570	296.33	

communication between the parties lead to no data being collected for one of the pilots. The data that was collected by the IC rollers did not align with the manually recorded data. Figure 2 is a screen shot of the temperature data displayed on VisionLink. It shows that over 95% of the temperatures at breakdown were below 200ºF. Figure 3 shows the manually recorded temperatures at breakdown. It can be seen that the actual temperatures were between 200-250ºF or above 250ºF. The data range on VisionLink was customized to provide a better visual understanding through the screenshot. The average temperature at breakdown captured through IC was approximately 160ºF.

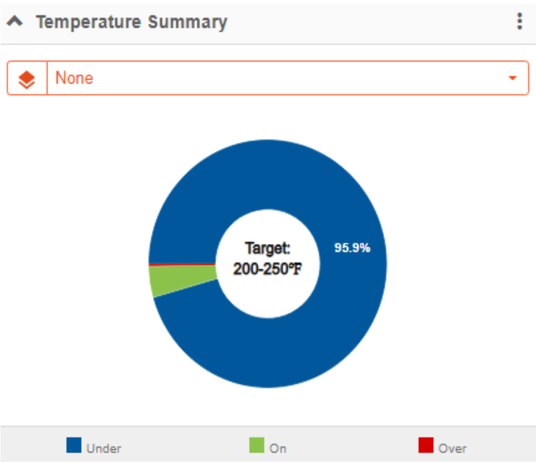

Figure 2. Temperature Summary, VisionLink

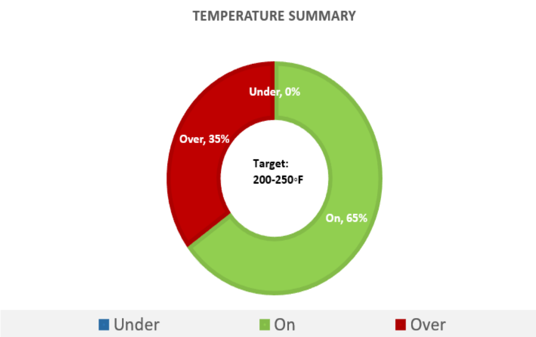

Figure 3. Temperature Summary, Manual

Inconsistent results were also noticed when comparing the roller pass counts between the IC and manually collected data. Figures 4 and 5 respectively show the pass count data as displayed on VisionLink, and the manually recorded pass counts. Similar to the temperatures, the pass counts recorded by IC were also significantly lower than what was noted in the field.

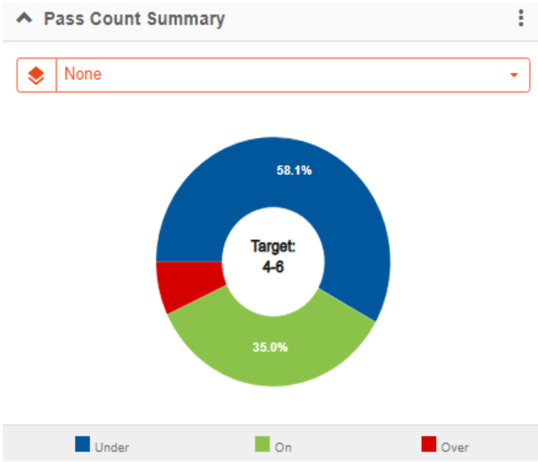

Figure 4. Pass Count Summary, VisionLink

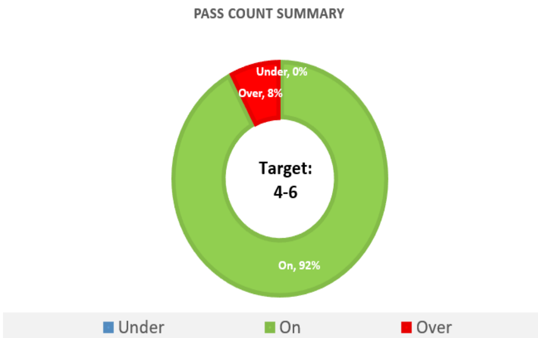

Figure 5. Pass Count Summary, Manual

Although Intelligent Compaction did not perform up to the expectations during this study, it has proved to be useful in other cases. The inconsistent data collected by the technology could have been caused by improper setup of the technology, miscommunication between the parties, and many other uncertainties that are present during construction projects.

5 Lessons Learned

The technologies discussed in this manuscript are still relatively new in the highway construction industry and the case study revealed many important lessons to take away for future use. First thing to note about all three technologies is that the most important step is to ensure that all aspects are setup prior to the project starting. There were many issues encountered throughout the project that showed lack of preparation by both the contractor and the technology vendors.

One major issue encountered with the e-ticketing technology was the setup of the Static GeoZone. As discussed previously, the purpose of this GeoZone was to record the time when the trucks arrived at the project site, in order to reduce wait times. However, the contractor failed to setup the GeoZone around either of the project sites and therefore no data was recorded in this category. Another crucial issue encountered with e-ticketing was that some of the trucks being used for deliveries did not have GPS transponders installed. Without the GPS transponders, the mobile GeoZone could not be utilized and thus dump times for those trucks were not recorded.

Regarding the paver mounted thermal profiler, the contracts stated that infrared cameras were to be setup on the paver, on top of the hopper, and on top of the screed. However, only the back of the paver cameras were successfully installed for both of the pilots. This was a huge loss for the study because seeing the temperatures in the hopper and screed could be one way to monitor effective workflows and future pavement failures. Further, the technology vendor was unsuccessful in providing access information for the online MOBA interface to the stakeholders prior to project startup, which delayed data analysis.

Finally, Intelligent Compaction had the most issues during the pilot projects. Lack of communication between the parties led to no IC data being collected from one of the pilots. The data that was retrieved was not consistent with the field findings. The contractor played a part in this due to the rushed schedule of the project, and the lack of transparency with the other stakeholders.

In general, most of the issues encountered during this study could have been solved easily through having open communication between the parties. If used properly, these technologies can benefit all stakeholders involved in the projects, but the parties must be willing to collaborate and change their attitudes towards technology to take full advantage of these tools.

6 Future Work

Veta is a standardized software for the use and analysis of Intelligent Compaction and Infrared (IR) technologies. This map-based tool can be used to view and analyze geospatial data that can be imported from IC machines and MOBA, Pave-IR scanners. This software is required in the AASHTO PP81-70 specifications and most DOT IC specifications. Additionally, Veta has been promoted by the pooled fund study TPF-5 (334) "Enhancements to the Intelligent Construction Data Management System (VETA) and Implementation." The goal behind this pooled fund study is to "provide a platform for states to engage in discussions and to share information to assist with moving these technologies to the next levels [11]." The collaboration and funding between 16 DOTs from the pooled fund is continuously enhancing the VETA software for easier implementation into the industry.

Although, this tool provides a great, singular platform to analyze IC and IR data, it has yet to incorporate e-ticketing. Having a fleet tracker and electronic documentation system would allow VETA to be the ideal software for tracking paving projects. Having a singular software that tracks all three technologies, would increase accessibility, and ease of use. The three technologies combined can have a tremendous impact on highway construction projects in the United States by boosting project efficiency and safety of the highway inspectors. Finally, contractors and equipment vendors would be more open to incorporating these technologies if they only have to manage one system rather than three different technologies.

7 Conclusions

According to the comparisons between the manually collected data and the electronic data, the technologies shows great potential in improving the efficiency of paving projects and improving project safety. For e-ticketing, and Pave-IR the results support the accuracy of the data as well as the time savings that come with the incorporation of technology into the work place. Although Intelligent Compaction did not perform up to the expectations for this particular case study, it has been successfully used by other DOTs and has shown great potential in improving project records and efficiency of roller operations.

This manuscript presents the application of three technologies which, if used properly can result in much safer and efficient paving projects. Having a strong and healthy culture of collaborating and partnering would significantly help further implement these technologies in the highway construction industry. E-ticketing can eliminate paper, enhance project records for all stakeholders and maintain safer projects. Pave-IR can increase the life of the pavement by providing instant detection of cold spots during the paving operations and also reducing maintenance costs. Lastly, Intelligent Compaction shows great potential of improving project records, and increasing pavement life by allowing consistent compaction during construction. Combining these technologies into a singular interface where all stakeholders can monitor project progress, and store project records will allow further implementation of technology in highway construction.

As the industry faces personnel reductions and resources, technologies such as the ones discussed here will have to be utilized as they offer a way to maintain quality and service on paving operations.

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