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E-CONSTRUCTION TECHNOLOGIES FOR EFFICIENT HIGHWAY CONSTRUCTION INSPECTIONS

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E-CONSTRUCTION TECHNOLOGIES FOR EFFICIENT HIGHWAY CONSTRUCTION INSPECTIONS

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in Civil Engineering in the
College of Engineering
at the University of Kentucky

By

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ABSTRACT OF THESIS

E-CONSTRUCTION TECHNOLOGIES FOR EFFICIENT HIGHWAY CONSTRUCTION INSPECTIONS

Over recent years, organizations such as the Federal Highway Administration and Departments of Transportation across the United States have showed interest in automating highway construction processes. The addition of e-Construction and other advanced technologies can significantly improve the efficiency and safety of highway paving operations, specifically paving inspections. Activities such as collecting load tickets, tracking pavement lay-down temperatures, and monitoring roller movement are antiquated practices that DOT inspectors perform during paving operations. E-Ticketing, Paver Mounted Thermal Profiling, and Intelligent Compaction were proposed to automate paving inspections and were recently tested in two resurfacing pilot projects in the state of Kentucky. Findings from the projects indicate that the three technologies display great potential in improving safety and efficiency of paving inspections. The contribution of this thesis is to document the research effort, evaluate the effectiveness of the technologies compared to the traditional practices, and discuss the lessons learned for industry practitioners.

KEYWORDS: E-Construction, E-Ticketing, Paver Mounted Thermal Profilers, Intelligent Compaction, Paving Operations.

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CHAPTER 1. BACKGROUND AND SCOPE OF WORK

1.1 Introduction

Construction is one of the biggest industries worldwide, and it has traditionally been slow to adopt technology. Today, advancements in computing, artificial intelligence (AI), and communications are allowing industries around the world to improve efficiency, safety, and reduce costs. The addition of these technologies in the global industry over recent decades has led to a positive change in business outcomes. The highway construction industry in the United States has been slower to adopt technology thus automating its current processes can lead to a significant improvement in efficiency and safety.

Recognizing this fact, the Federal Highway Administration (FHWA) and the Departments of Transportation (DOTs) in the United States are taking steps to incorporate technologies in highway construction operations. In 2015, the Fixing America's Surface Transportation Act (FAST Act) was signed into law, and a part of this act included the Technology and Innovation Deployment Program (TIDP) [1]. This program was designed to fund efforts to accelerate the incorporation of innovations and technologies that benefit aspects of highway transportation including highway construction [1]. One way the industry is looking to incorporate innovations is through adding e-Construction and other similar technologies to further improve efficiency, safety, and reduce employee workload.

The FHWA defines e-Construction as "The creation, review, approval, distribution, and storage of highway construction documents in a paperless environment [2]." E-Construction has been promoted heavily by the FHWA through their Every Day Counts (EDC) model. EDC is defined as "A state based model that identifies and rapidly deploys proven, yet underutilized innovations to shorten the project delivery process, enhance roadway safety, reduce traffic congestion, and integrate automation [3].” The promotion of e-Construction in EDC-3 in 2015, and EDC-4 in 2017 has led to many DOTs and transportation agencies sharing their e-Construction practices through activities such as webinars and peer exchange reports [2]. The addition of e-Construction and other advanced technologies can aid in maintaining a high quality and service while simultaneously improving efficiency and safety of highway construction projects.

A specific area of highway construction that can be improved drastically through the addition of technology is paving inspections. Activities such as collecting load tickets, recording pavement temperatures, and monitoring roller movement during paving operations all fall under paving inspections. This crucial aspect of paving projects can significantly impact the performance of a pavement and is often given little attention due to the fast paced nature of paving operations and the inspectors having to cover multiple projects at once. Technology exists to collect this information automatically allowing for safer and more efficient paving operations. As a part of the Kentucky Transportation Cabinet’s (KYTC) efforts to incorporate e-Construction in its projects, the Kentucky Transportation Center (KTC) was awarded funding to fill an important void of tying multiple e-Construction technologies together to further improve safety and efficiency of paving projects. The technologies described in this report were tested in two pilot projects in KYTC’s District 7 and the goal of this thesis is to summarize the research effort, document the results, and discuss the lessons learned from the pilot projects for industry practitioners.

1.2 Study Scope and Objectives

The study was coordinated with the staff of KYTC District 7 to test technologies complimenting the typical duties of the highway construction inspection personnel. Although a typical paving operation includes many activities such as: milling, plant operations, traffic control, striping etc. The focus of this study was to improve the processes that are not experience/skill dependent, and could easily be automated. The scope of this study included ticket handling, tracking mat temperatures, and monitoring roller operations. The traditional practices associated with these activities are extremely inefficient and unsafe for the inspectors. The technologies proposed to automate these activities and improve efficiency and safety of the operations are: e-Ticketing, Paver Mounted Thermal Profiling, and Intelligent Compaction (IC). These technologies have previously been tested in highway construction projects but the industry has yet to combine them to provide one package to achieve automated paving inspections.

The overall purpose of this study was to improve the efficiency and safety of highway paving operations. The research focused on evaluating the technologies through data accuracy, and the time savings that come with the incorporation of technology into a process. The following objectives were set to ensure that the overall goal of the study was achieved:

1. Evaluate performance of e-Ticketing for construction inspections
2. Evaluate performance of other e-Construction related technologies (such as paver mounted thermal profilers and intelligent compaction)
3. Conduct pilot project rollout of selected inspection technologies
4. Provide guidance on scalability and implementation of inspection technologies

The implementation of the overall objective of the study is to have the proposed technologies, if proven useful, in the KYTC Standard Specifications for highway construction. Complete integration of the proposed technologies may require further research efforts.

CHAPTER 2. LITERATURE REVIEW

This section of the report provides a background of the technologies used for the study. Existing literature was reviewed to capture an overview of the state-of-practice of the technologies in the United States.

2.1 Electronic Ticketing

The process of physically collecting load delivery tickets from trucks at paving operations is an antiquated practice that exposes the inspectors to many safety threats. The paving inspectors face many hazardous situations while collecting the load tickets from activities such as walking adjacent to traffic, climbing the side of the delivery trucks for ticket retrieval, and working in close proximity to heavy equipment. Electronic ticketing or E-ticketing technology exists which records the same information found on the traditional paper tickets automatically improving the efficiency and safety of paving operations.

Although electronic tickets have existed for some time in various industries, it is a relatively new concept in highway construction. In the United States, e-Ticketing was first brought in the spotlight by Iowa Department of Transportation (IowaDOT). Iowa started the process of incorporating e-Ticketing in its highway paving projects in 2015 and conducted multiple pilots during the paving season. The results were extremely promising and in 2016, IowaDOT successfully achieved 100% paperless processes on a construction project [4]. The e-Ticketing efforts of Iowa were highlighted in EDC-3 under e-Construction and the agency shared their experience with other DOTs through both in-person and virtual peer exchanges [5].

Pennsylvania Department of Transportation (PennDOT) piloted e-Ticketing in 2017. PennDOT's District 11 added a special provision for the pilot requiring GPS trackers on all equipment allowing for easier tracking of all machinery associated with the project [6]. The pilot resulted in a special provision of "Electronic Delivery Management System for HMA/WMA Material" [6]. Following the success of the first project, the agency planned three additional e-ticketing pilots in District 11 for 2018. The state-of-practice of e-ticketing across the country is still not clear, however a few other states including, Virginia, North Dakota, and Alabama have tested e-ticketing for asphalt paving, and agree that electronic ticketing provides "efficiency gains and jobsite safety improvements in work zones [7]."

E-ticketing provides the ability for the inspectors to do more than just collect load delivery tickets. Through this technology, the inspectors have the ability to track all equipment, schedule load deliveries to further reduce wait times in front of the paver, and calculate yield tonnages remotely. Overall, the addition of e-ticketing in highway paving has resulted in projects that are much more efficient and in-general, safer for the inspectors.

2.2 Paver Mounted Thermal Profilers

One of the important jobs that the DOT construction inspectors are tasked with during paving operations is measuring mat temperatures. This key task ensures longevity of the pavement because lower lay-down temperatures usually indicate poor performance of the mat. Traditionally, this task is done using hand-held temperature guns in the field to ensure adequate mat temperatures are achieved, and to identify any insolated areas on the fresh pavement. Paver mounted thermal profilers are thermal cameras that are usually mounted on the back of the paver, and provide a continuous temperature reading of the mat. Additionally, the infrared cameras can also be attached on top of the hopper and the screed to track that temperature of the mix being delivered to the project.

Texas DOT (TxDOT) was the first to use infrared technology to test thermal segregation on asphalt mats in the year 2000. This research effort showed promising results, and eventually led to the development of Pave-IR, an automatic method for recording pavement temperatures using thermal sensors on the back of the paver [8]. The success of this technology has led TxDOT to implement Pave-IR into their HMA specifications as it provides real-time reading of mat temperatures for the paving crews and it allows for an automatic storage of temperature data for the DOT to examine if failures are noticed. The current TxDOT HMA specification includes Tex-244-F, which implements Pave-IR as a standard test method for all HMA paving operations [8]. In addition to the TxDOT efforts, Pave-IR has also been promoted by SHRP 2 as a solution to enhance quality control on asphalt pavements [9]. If used properly, this technology can enhance the efficiency of paving projects by allowing the crews to instantly fix cold spots on the fresh pavement, and by allowing the inspectors to cover multiple projects concurrently.

2.3 Intelligent Compaction

Compaction is an important process in asphalt pavement construction. Proper compaction is necessary to achieve a high quality pavement, which results in a longer lasting road. The traditional method of compacting the fresh pavement can result in non-uniform compaction because it solely relies on the experience of the roller operator. Intelligent Compaction (IC) technology tracks roller movement including passes and temperatures of the mat. This technology displays the data on a LED screen mounted in the roller hub to assist the operator achieve uniform compaction. Additionally, IC allows for an instant storage of the roller compaction data for the client to examine.

Intelligent Compaction has been in the market since 2008 and many state DOTs, the FHWA, and commercial entities have demonstrated the significance of IC [10]. One key demonstration was the FHWA's Transportation Pooled Fund (TPF) study conducted from 2008 to 2010. During the study, 13 DOTs collaborated to test and evaluate IC technologies through conducting pilot projects [11]. The study showed that IC could be successfully used as a method to track roller movement and pavement temperatures to achieve better compaction than the traditional methods [11].

CHAPTER 3. METHODOLOGY

The goal of this study was to improve the overall efficiency and safety of highway paving projects through the introduction of e-Construction technologies. The expectation was that the analysis of the data collected from the two pilot projects would show that the technologies in question could work well together to reduce inspector workload and improve project safety. The two pilot projects are both located in KYTC District 7 in Fayette County. Project A was on New Circle Road (KY 4), and Project B was on Newtown Pike (KY 922), and the work type for both projects was described as asphalt resurfacing. Data collection comprised of both traditional methods and through the technologies. For the traditional methods, data was collected the same way the inspectors would traditionally. The same data was also collected through the technologies that were being tested during the pilots. The results from data collection were then compared for data accuracy and time savings. The following sections provide a detailed description of the methodology and analysis of the three technologies.

3.1 E-Ticketing

E-Ticketing technology improves the efficiency and safety of highway construction projects by providing a paperless system. Earthwave technologies based out of Indianapolis, IN is an industry leader for e-Ticketing in highway construction, and they were contracted to setup an e-Ticketing program for the study by the contractor. First, Earthwave installed GPS transponders on all equipment associated with the two pilot projects. The GPS transponders worked in conjunction with Earthwave's online interface called Fleetwatcher, where they were displayed on a GIS-based map. In addition to tracking all equipment, Fleetwatcher allows clients to view load cycle times and delivery tickets.

The first step of setting up Earthwave's e-Ticketing program is creating GeoZones around the project sites and the asphalt plant. GeoZones are geo-fences that notify the system when a GPS transponder enters or exists their parameter. For the study, two types of GeoZones were planned for each project. The first is called a Static-GeoZone, which is usually setup around the proposed project site. When a dump truck with a GPS transponder enters the Static-GeoZone, the system records that time as the time at which the truck arrived at the project site. The second GeoZone is called a Mobile-GeoZone, which is significantly smaller than the Static-GeoZone and is setup around the paver or the material transfer vehicle (MTV). When a truck enters or exits the Mobile-GeoZone, that time is recorded as the time at which the truck dumped the load. These GeoZones provide an additional level of detail that can help schedule deliveries to reduce wait times in front of the paver.

As far as load delivery information is concerned, each e-ticket contains the same information found on traditional ticket such as: Ticket Number, Ticket Date/Time, Material Type, Total Tons Delivered, and Net Tons. In addition to the general load information, e-Tickets provide the dump coordinates, recorded by the Mobile-GeoZone. All e-Tickets can be accessed by authorized project personnel on the Fleetwatcher website, or remotely on the Fleetwatcher app, eliminating the need to handle and track paper tickets. For the study, the paper tickets were collected by KYTC inspectors, the information on the tickets and the time to retrieve the ticket/load information was recorded in the field. The same load ticket was then retrieved through Fleetwatcher and time to retrieve the information was recorded. Following project completion, the data from the two collection methods was compared for content accuracy and time savings to assess the effectiveness of e-Ticketing in improving efficiency and safety.

Another benefit of using e-Ticketing over paper tickets is that it allows the inspectors track theoretical tonnages in a much more efficient manner. Theoretical tonnage is a calculation that DOT inspectors perform to estimate the amount of material that should be used for a given pavement length. When compared to the cumulative tons delivered to a project, the theoretical value can confirm if the crews are paving in accordance with the specifications, and it ensures that material is not being dumped along the process. Equation 1 shows the calculation for the theoretical tonnage.

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

This equation considers material properties, and the pavement dimensions to estimate the theoretical tons. Typically, the inspectors use station markings along a project site to estimate the pavement length. This way to estimating the paving distance can be inaccurate and take a significant amount of time. For the study, rather than using station markings, the dump coordinates available on Fleetwatcher were used along with the “Measure” tool in Google Earth to estimate pavement lengths. The calculated theoretical tons were compared to the cumulative tons to track project productivity.

3.2 Pave-IR

Pave-IR technology provides continuous tracking of pavement temperatures along with an automatic storage of the project data for record keeping. For the study, MOBA Mobile Automation were contracted to setup a Paver-IR program. The contract language stated that MOBA would setup thermal sensors on the back of the paver to provide tracking of mat temperatures, as well as thermal sensors on top of the screed and hopper to track the temperatures of loads being delivered to the projects. Unfortunately, due to communication issues between parties, only the sensors on the back of the pavers were setup prior to the projects starting. The installed cameras displayed the mat temperatures in real-time on LED screens mounted on the pavers, which allowed the crews to instantly identify and fix cold spots on the mat. The thermal recordings are also uploaded to MOBA's online cloud, or automatically stored on a remote storage device (USB storage) if there is a loss of cellular signal.

To assess the accuracy of the data being captured by the Pave-IR technology, mat temperatures at various locations were measured using traditional infrared guns, and the GPS coordinates at the locations were recorded in the field. Once the pilot projects had ended, the data from the MOBA Cloud was retrieved and the temperatures recorded by the technology were compared to the manually recorded temperatures for data accuracy. Pave-IR eliminates the need for inspectors to perform the task of manually checking mat temperatures throughout the project, and thus eliminating a significant amount of time that they are exposed to hazards by standing next to moving traffic, high mat temperatures, and heavy equipment. Additionally, Pave-IR allows the DOTs to have an improved record keeping system that they can review if failures are noticed in the pavement.

3.3 Intelligent Compaction

Intelligent Compaction rollers assist the operators achieve better compaction thus improving the service life of the mat. For the study, SITECH Solutions were contracted to retrofit the rollers for each project with the Intelligent Compaction technology. IC technology tracks roller movements, and displays it on an LED screen mounted in the roller hub. Additionally, the technology also records temperatures of the mat at breakdown. Similar to the Pave-IR technology, the data is automatically uploaded to a cloud server for ease of access. Traditionally, the inspectors have to keep track of roller movement during a resurfacing project to ensure proper compaction is achieved. IC offers a way for this process to be automated, allowing the inspectors to focus on more skill demanding tasks.

Concerning data collection for the study, the roller passes and the temperatures at various locations were recorded manually throughout the project. The IC technology recorded the same information simultaneously and provided a real time display for the roller operators. Following project completion, the manually recorded data was compared to the IC data for accuracy. The benefits associated with IC are similar to Pave-IR in that it allows the inspectors to cover multiple projects at once, and improves project records for the DOTs.

CHAPTER 4. RESULTS

Following project completion, the data collected in the field was analyzed to assess the ability of the technologies to improve efficiency and safety of paving projects. The following section will discuss the data analysis process for each technology and report the findings.

4.1 E-Ticketing

To assess the accuracy of the data captured by Fleetwatcher, the electronically collected data was compared to the data recorded from traditional tickets. When comparing the accuracy of the information captured through the technology, it was found that the data alignment was perfect for the following categories: Truck Number, Material Mix, Ticket Number, Net Tons, and Cumulative Tons. Table 4.1 shows a small sample of data from one shift of the project, but it is illustrative of all load tickets collected throughout the pilots (Appendix 2). In Table 1, the “Conventional” data was gathered from physical tickets whereas the “Technology” data was gathered from Fleetwatcher:

Table 4.1: Data Alignment

Date: 07/05/2018					
Data	Truck Number	Mix Design	Ticket Number	Net Ticket Tons	Cumulative Tons
Conventional	PT155	CL4 S .38 A76	868816	26.42	206.76
Technology	PT155	CL4 S .38 A76	868816	26.42	206.76
Conventional	H87	CL4 S .38 A76	868818	25.61	232.37
Technology	H87	CL4 S .38 A76	868818	25.61	232.37
Conventional	H94	CL4 S .38 A76	868821	25.60	257.97
Technology	H94	CL4 S .38 A76	868821	25.60	257.97
Conventional	PR08	CL4 S .38 A76	868828	25.99	309.64
Technology	PR08	CL4 S .38 A76	868828	25.99	309.64

In addition to data accuracy, e-Ticketing technology improves the safety of paving projects through reducing inspector exposure time. It takes a significant amount of time for the inspectors to retrieve the physical tickets from each delivery truck and during that time, the inspectors are typically walking adjacent to fast moving traffic, and heavy backing equipment. Throughout the projects, it was noticed that the time to retrieve the information from FleetWatcher was significantly faster than the traditional method. For one shift, it was recorded that it took the inspector 54 minutes to retrieve 19 tickets. The same information was then collected from Fleetwatcher in approximately 18 minutes. This significant amount of time saved can be spent on other tasks that require more skill or inspector experience. Additionally, e-Ticketing allows the inspectors to retrieve ticket information from the safety of their trucks, thus eliminating the field safety hazards.

The final aspect of e-Ticketing technology tested during the pilots was its ability to calculate theoretical tonnages more efficiently. Although the theoretical estimates never match up exactly with the cumulative tons delivered due to the many uncertainties present at construction projects, huge variations between the two values could indicate that the mix is going to waste at some point along the process. Many theoretical estimates were calculated using the method discussed previously, and a small sample is shown in Table 4.2.

Table 4.2: 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	6954.89	14	1.25	110	743.79	754.44

Furthermore, a theoretical tonnage value was calculated for each load delivery and compared to the cumulative tons given on the load ticket. For an accurate comparison, a statistical analysis was performed on the tonnage data. A paired samples t-test compares two means that are from the same object or related units, and is ideal for situations where a statistical difference between two measurements is needed. Due to the nature of the data, and a total sample size of 75, a paired samples t-test was conducted to see if there is any statistical difference between the theoretical tonnages and the cumulative tons delivered (Appendix 2). Table 4.3 shows the results of the paired t-test.

Table 4.3: Theoretical v. Actual Paired T-Test Results

Pair	Mean	Standard Deviation	Standard Error Mean	t	df	P(2-tailed)
Theoretical v. Actual	0.710	20.810	2.403	0.296	74	0.768

The null hypothesis of a paired samples t-test is that the true mean difference is zero, and the alternative hypothesis being that the true difference is not zero. The test resulted in a P value of 0.768, which indicates that the null hypothesis cannot be rejected, and thus showing that there is no significant difference between the theoretical tons estimated using e-Ticketing and the cumulative tons delivered. Overall, the results indicate that incorporation of e-Ticketing into paving projects could significantly improve the efficiency of the inspections and safety of the DOT inspectors.

4.2 Paver-IR

Using Pave-IR technology to track mat temperatures proved to be much more efficient and safe than the traditional method. Following project completion, the manually measured temperatures were compared to the Pave-IR temperatures to assess the accuracy of the data captured through the technology. It was found that Pave-IR successfully captured continuous and accurate mat temperatures. Figure 4.1 is a screenshot from the Pave-IR interface displaying a continuous reading of temperatures.

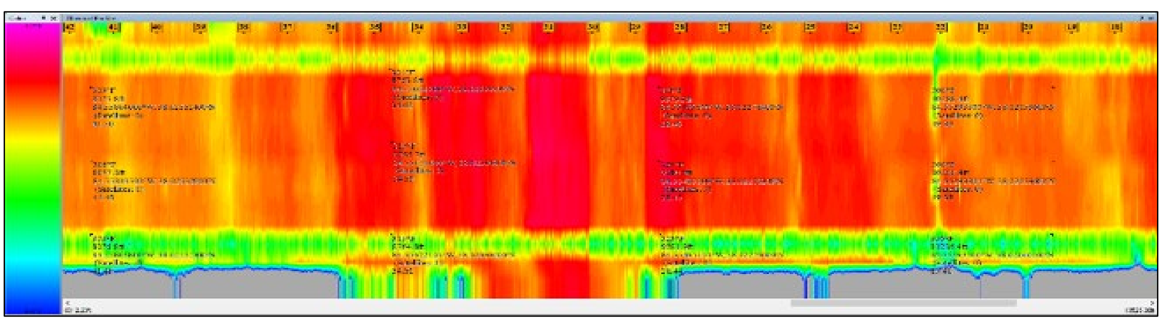


Figure 4.1: Pave-IR Interface

To evaluate data accuracy, the coordinates where mat temperatures were recorded manually were mapped on the Pave-IR interface to retrieve the Pave-IR temperatures at those locations. Table 4.3 shows a small sample of the data where the “Conventional” temperatures were recorded using a traditional infrared gun, and the “Technology” temperatures were captured through Pave-IR. The percent differences show that there is no significant difference between the two methods of retrieving mat temperatures (complete temperature data is found in Appendix 3). Additionally, Pave-IR improves the safety and project records through eliminating the need for inspectors to be physically present at the project site, and providing automatic storage of the temperatures.

Table 4.4: Temperature Alignment

Method	Latitude	Longitude	Average Temp (ºF)	Percent Difference (%)
Conventional	38.043	-84.567	297.33	0.78
Technology	38.043	-84.566	299.67	
Conventional	38.0417	-84.567	290.00	1.78
Technology	38.042	-84.567	295.27	
Conventional	38.0396	-84.568	293.00	1.12
Technology	38.04	-84.57	296.33	
Conventional	38.0338	-84.5663	298.67	0.11
Technology	38.034	-84.566	298.33	
Conventional	38.0313	-84.5641	306.67	0.65
Technology	38.0313	-84.5642	304.67	
Conventional	38.0253	-84.558	296.33	3.16
Technology	38.0253	-84.558	306.00	
Conventional	38.024	-84.5562	303.67	2.57
Technology	38.024	-84.553	311.67	

Furthermore, another paired samples t-test was performed on the temperature data to unveil any statistical differences between the manually recorded temperatures and the

Pave-IR temperatures (Appendix 3). A total of 36 average temperature samples were used for the statistical analysis, and the results of the paired t-test are given in Table 4.5:

Table 4.5: Pave-IR v. Conventional Paired T-Test Results

Pair	Mean	Standard Deviation	Standard Error Mean	t	df	P(2-tailed)
Pave-IR v. Conventional	5.43	5.83	0.97	5.59	35	2.66E-06

The extremely small P value indicates that there is a statistically significant difference between the two categories. The Pave-IR technology appears to be measuring higher temperatures than the conventional infrared guns. The average difference of approximately 5 degrees Fahrenheit could be a result of multiple factors. One main factor that could influence the difference in temperatures is time difference between the two recordings. The technology records the mat temperatures instantly as the mat is laid, whereas the infrared gun temperatures are measured a later once the paver has moved past that spot. Furthermore, the project took place over night, the cool ambient temperatures and any type of wind could significantly affect the surface temperatures. The difference, although statistically significant, is expected due to the variety of factors that affect mat temperatures. The temperatures recorded through Pave-IR are accurate enough for all practical purposes.

4.3 Intelligent Compaction

While retrieving the Intelligent Compaction data from SITECH's online interface called VisionLink, it was noticed that only data from the New Circle Road (KY-4) project was captured by the technology. Furthermore, the analysis of the retrieved data showed that Intelligent Compaction did not provide accurate readings of mat temperatures at breakdown, and roller passes when compared to the manually collected data. Figure 4.2 shows the temperature data recorded by the IC sensors mounted on the breakdown roller. It can be seen that over 95% of the mat temperatures were under 200ºF. Figure 4.3 shows the breakdown temperatures that were manually recorded at the project site. It can be seen that the actual mat temperatures were 200ºF or above during breakdown.

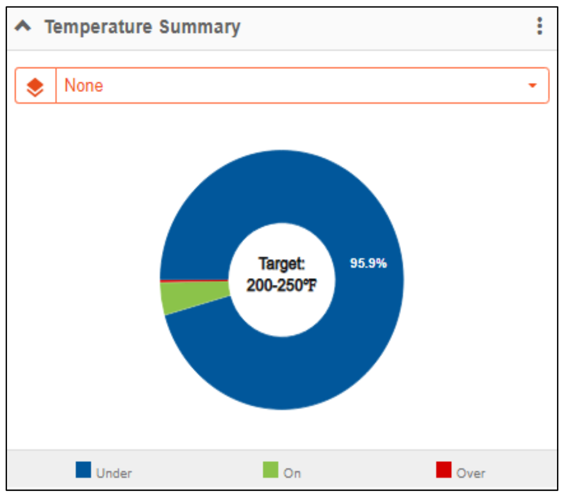


Figure 4.2: Breakdown Temperature Summary: IC

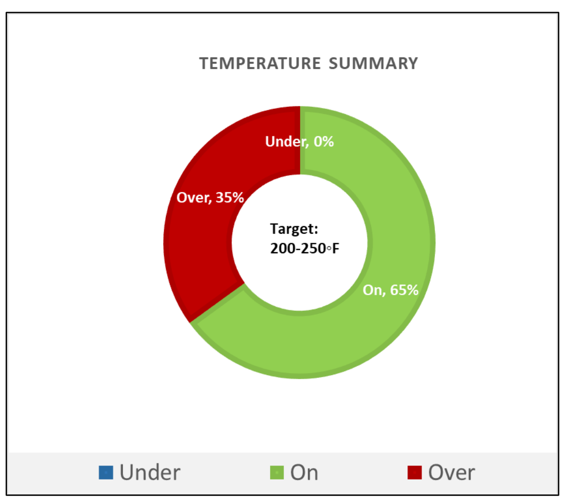


Figure 4.3: Breakdown Temperature Summary: Manual

Inaccurate results were also noticed when comparing the pass counts captured through IC and the manually recorded pass counts. Figure 4.4 shows the pass count data displayed on VisionLink and Figure 4.5 shows the manually recorded data. Similar to the temperatures, the technology-captured data was significantly different from the data captured in the field. Although IC did not perform up to the expectations for this particular study, it has proven to be a useful tool for many DOTs to improve project efficiency and safety. The inaccurate IC recordings could have been a result of miscommunication between stakeholders, errors during equipment setup, and a variety of uncertainties associated with highway construction projects.

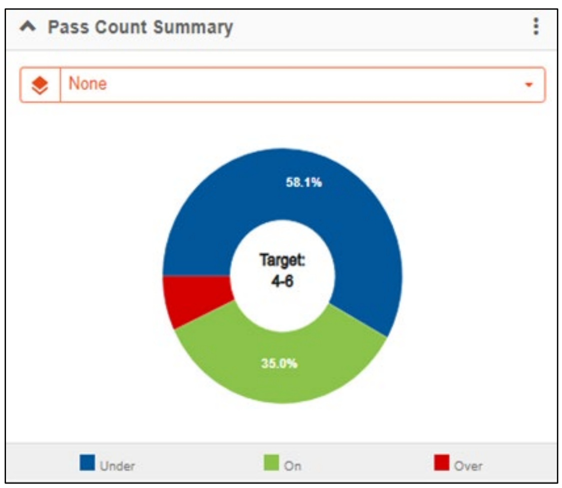


Figure 4.4: IC Pass Counts

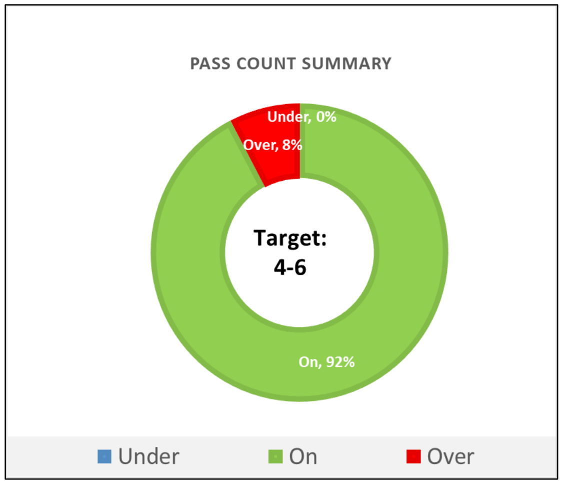


Figure 4.5: Manual Pass Counts

CHAPTER 5. LESSONS LEARNED

This study showed that the incorporation of e-Construction in paving operations could lead to a significant improvement in project efficiency and safety. There are many important lessons to take away from this research effort, and this section will discuss the lessons learned. All technologies tested during the study revealed key areas to improve upon for future projects. The first major take away is that when dealing with e-Construction, it is vital to setup and test all aspects of the technologies prior to the project starting. Due to the fast paced nature of resurfacing jobs, many parts of the setup were delayed until right before the projects started and this lead to many unnecessary issues that showed a lack of preparation from the various parties involved.

The major issue encountered with e-Ticketing was the setup of the Static-GeoZone around the project site. This GeoZone is a crucial tool since it can help schedule deliveries to the project to reduce wait times in front of the paver. For both projects, the Static-GeoZone was never setup and therefore the system did not collect arrival time data. A second key issue with e-Ticketing was that some of the trucks used for delivering asphalt to the project sites did not have GPS transponders installed, and therefore those trucks were not tracked by Fleetwatcher. These two issues could have been solved easily through proper setup of the technology.

Regarding Pave-IR, the thermal sensors for paver-screed, and hopper were not installed at either projects. The goal behind having the additional sensors was to record temperatures of the loads that were being delivered to the project from the plant to monitor effective workflows and future pavement failures. Furthermore, data analysis was delayed due to the researchers not having access information to the Pave-IR interface. Intelligent

Compaction had the most issues during this particular study. No IC data was collected for the Newtown Pike (KY 922) project and the data that was retrieved from the New Circle Road (KY 4) project was inconsistent with the field findings. Factors such as the rushed schedule of the project, miscommunications between the parties, and errors during equipment setup could have led to the problems associated with Intelligent Compaction.

All problems encountered during this study could have been solved easily through having open communication channels and transparency between the parties. The technologies are designed benefit all parties equally, but everyone involved must be willing to collaborate to take full advantage of these tools.

CHAPTER 6. CONCLUSIONS

The results of this study indicate that the technologies display great potential in improving safety and efficiency of paving inspections. Analysis of e-Ticketing and Pave-IR data shows that the technologies provide the same information, traditionally tracked by the inspectors, in a much more safe and efficient manner. Although the Intelligent Compaction results were inconsistent with the manually recorded data for this study, this technology has proven to be an important tool for other DOTs over the years. Any issue encountered throughout the projects, and during data analysis were a result of human errors, and not due to defects in the technologies.

This report shows that e-Construction technologies, if used properly, can significantly improve the efficiency and safety of paving operations and inspections. E-Ticketing provides an approach to eliminate paper from the construction process, and simultaneously improve DOT project records. Pave-IR and Intelligent Compaction can positively influence the pavement life by assisting the crews with finding and fixing pavement defects instantly, and improve project records through providing automatic storage. All three technologies provide a way for inspectors to shift their focus on tasks that demand their skills and experience.

It is crucial that all parties involved collaborate and partner on e-Construction projects to take full advantage of these technologies. This study shows that the three technologies can work well together, and combining them into a singular interface can help further implement them in the industry. As the demand for more efficient and safe construction projects increases, e-Construction offers the perfect solution while maintaining the quality and service of the projects.

APPENDICES

APPENDIX1. SAMPLE DATA COLLECTION SHEETS

Project:		Date:		Time:		Stations:		
E-Ticketing			E-Ticketing			E-Ticketing		
Data	Conventional	Technology	Data	Conventional	Technology	Data	Conventional	Technology
Truck Number			Truck Number			Truck Number		
Mix Design			Mix Design			Mix Design		
Ticket Number			Ticket Number			Ticket Number		
Time Batched			Time Batched			Time Batched		
Time On Site			Time On Site			Time On Site		
Time Dumped			Time Dumped			Time Dumped		
Tons for this ticket			Tons for this ticket			Tons for this ticket		
Cumulative Tons			Cumulative Tons			Cumulative Tons		
Time to Acquire Data			Time to Acquire Data			Time to Acquire Data		

Project:		Date:		Time:		Stations:		
Pave-IR			Pave-IR			Pave-IR		
Data	Conventional	Technology	Data	Conventional	Technology	Data	Conventional	Technology
Temp in Hopper (Station)			Temp in Hopper (Station)			Temp in Hopper (Station)		
Temp at Screed (Station)			Temp at Screed (Station)			Temp at Screed (Station)		
Mat Temp, RT (Station)			Mat Temp, RT (Station)			Mat Temp, RT (Station)		
Mat Temp, CNT (Station)			Mat Temp, CNT (Station)			Mat Temp, CNT (Station)		
Mat Temp, LT (Station)			Mat Temp, LT (Station)			Mat Temp, LT (Station)		
Time to Acquire Data			Time to Acquire Data			Time to Acquire Data		

***NOTE: For temperatures, record the average of 3

Project:			Date:		Time:	Stations:		
Intelligent Compaction			Intelligent Compaction			Intelligent Compaction		
Data	Conventional	Technology	Data	Conventional	Technology	Data	Conventional	Technology
Roller Coverage (STA to STA, # of passes, roller overlap)			Roller Coverage (STA to STA, # of passes, roller overlap)			Roller Coverage (STA to STA, # of passes, roller overlap)		
Avg. Temp. at Breakdown (every 25’ @ RT, CNT, LT)			Avg. Temp. at Breakdown (every 25’ @ RT, CNT, LT)			Avg. Temp. at Breakdown (every 25’ @ RT, CNT, LT)		
Relative Density (Station)			Relative Density (Station)			Relative Density (Station)		
Relative Density (Station)			Relative Density (Station)			Relative Density (Station)		
Time to Acquire Data			Time to Acquire Data			Time to Acquire Data		

APPENDIX 2. E-TICKETING DATA

E-Ticketing	Date: 07/02/2018								
Data	Truck Number	Mix Design	Ticket Number	Time Batched	Time on Site	Time Dumped	Net Ticket Tons	Cumulative Tons	Approx. Time to Acuqire Data (mins)
Conventional	PR08	CLE .38 A 76	868460	20:40		20:53	25.88	949.43	5:00
Technology	PR08	CLE .38 A 76	868460	20:40		20:56	25.88	949.43	2:00
Conventional	PT155	CLE .38 A 76	868447	20:07		20:25	25.05	821.93	6:00
Technology	PT155	CLE .38 A 76	868447	20:07		20:28	25.05	821.93	2:00
Conventional	H98	CLE .38 A 76	868455	20:21		20:43	25.21	898.39	6:00
Technology	H98	CLE .38 A 76	868455	20:21		20:44	25.21	898.39	2:00
Conventional	RR57	CLE .38 A 76	868470	21:04		21:27	25.92	1076.07	3:38
Technology	RR67	CLE .38 A 76	868470	21:04		21:29	25.92	1076.07	2:30
Conventional	CB25	CLE .38 A 76	868479	21:35		22:41	25.64	1178.37	2:30
Technology	CB25	CLE .38 A 76	868479	21:35		-	25.64	1178.37	1:45
Conventional	H97	CLE .38 A 76	868490	22:01		22:49	25.21	1254.30	6:00
Technology	H97	CLE .38 A 76	868490	22:01		-	25.21	1254.30	< 1:00
Conventional	CB25	CLE .38 A 76	868499	22:32		11:25	25.65	1356.32	7:00
Technology	CB25	CLE .38 A 76	868499	22:32		11:25	25.65	1356.32	1:30
Conventional	H98	CLE .38 A 76	868493	22:10		23:02	25.23	1305.58	5:00
Technology	H98	CLE .38 A 76	868493	22:10		23:04	25.23	1305.58	<1:00
Conventional	H99	CLE .38 A 76	868497	22:25		23:16	25.09	1330.67	5:00
Technology	H99	CLE .38 A 76	868497	22:25		23:20	25.09	1330.67	<1:00
Conventional	RR57	CLE .38 A 76	868536	0:20		0:35	26.04	102.14	2:00
Technology	RR57	CLE .38 A 76	868536	0:20		0:41	26.04	102.14	<1:00
Conventional	H98	CLE .38 A 76	868538	0:24		0:43	25.24	127.38	2:00
Technology	H98	CLE .38 A 76	868538	0:24		0:45	25.24	127.38	<1:00
Conventional	PR08	CLE .38 A 76	868540	0:28		0:50	26.07	153.45	2:00
Technology	PR08	CLE .38 A 76	868540	0:28		0:50	26.07	153.45	<1:00
Conventional	PI155	CLE .38 A 76	868548	0:56		1:22	24.97	255.29	2:00
Technology	PI155	CLE .38 A 76	868548	0:56		1:25	24.97	255.29	<1:00
Conventional	H98	CLE .38 A 76	868553	1:13		1:37	25.17	331.85	3:00
Technology	H98	CLE .38 A 76	868553	1:13		1:39	25.17	331.85	<1:00
Conventional	PR08	CLE .38 A 76	868554	1:16		1:43	26.03	357.88	2:00
Technology	PR08	CLE .38 A 76	858554	1:16		1:49	26.03	357.88	<1:00
Conventional	H99	CLE .38 A 76	868556	1:38		1:58	25.18	408.83	2:00
Technology	H99	CLE .38 A 76	868556	1:38		2:00	25.18	408.83	<1:00
Conventional	PR06	CLE .38 A 76	868557	1:40		2:02	26.01	434.84	2:00
Technology	PR06	CLE .38 A 76	868557	1:40		2:07	26.01	434.84	<1:00

E-Ticketing	Date: 07/05/2018								
Data	Truck Number	Mix Design	Ticket Number	Time Batched	Time on Site	Time Dumped	Net Ticket Tons	Cumulative Tons	Approx. Time to Acuqire Data (mins)
Conventional	CB25	CL4 S .38 A76	868794	0:13		0:34	25.72	51.30	5:34
Technology	CB25	CL4 S .38 A76	868794	0:13		-	25.72	51.30	<1:00
Conventional	PR10	CL4 S .38 A76	868807	0:50		1:18	26.06	103.48	2:00
Technology	PR10	CL4 S .38 A76	868807	0:50		-	26.06	103.48	<1:00
Conventional	PMT211	CL4 S .38 A76	868807	0:58		1:22	26.35	129.83	2:00
Technology	PMT211	CL4 S .38 A76	868807	0:58			26.68	129.83	<1:00
Conventional	H98	CL4 S .38 A76	868811	1:08		1:28	25.30	155.13	2:30
Technology	H98	CL4 S .38 A76	868811	1:08		1:31	25.3	155.13	<1:00
Conventional	H99	CL4 S .38 A76	868815	1:15		1:35	25.21	180.34	2:00
Technology	H99	CL4 S .38 A76	868815	1:15		1:39	25.21	180.34	<1:00
Conventional	PT155	CL4 S .38 A76	868816	1:23		1:44	26.42	206.76	2:00
Technology	PT155	CL4 S .38 A76	868816	1:23		1:48	26.42	206.76	<1:00
Conventional	H87	CL4 S .38 A76	868818	1:32		1:51	25.61	232.37	2:00
Technology	H87	CL4 S .38 A76	868818	1:32		-	25.61	232.37	<1:00
Conventional	H94	CL4 S .38 A76	868821	1:39		1:58	25.60	257.97	2:00
Technology	H94	CL4 S .38 A76	868821	1:39		2:00	25.60	257.97	<1:00
Conventional	PR08	CL4 S .38 A76	868828	1:58		2:14	25.99	309.64	1:00
Technology	PR08	CL4 S .38 A76	868828	1:58		2:17	25.99	309.64	<1:00
Conventional	H93	CL4 S .38 A76	868830	2:06		2:26	25.91	335.55	<1:00
Technology	H93	CL4 S .38 A76	868830	2:06		2:29	25.91	335.55	<1:00
Conventional	PR06	CL4 S .38 A76	868832	2:16		2:34	26.08	361.63	<1:00
Technology	PR06	CL4 S .38 A76	868832	2:16		-	26.08	361.63	<1:00
Conventional	H97	CL4 S .38 A76	868834	2:32		2:48	25.38	412.96	2:00
Technology	H97	CL4 S .38 A76	868834	2:32		2:51	25.38	412.96	<1:00
Conventional	PT155	CL4 S .38 A76	868835	2:44		3:00	26.41	439.67	2:00
Technology	PT155	CL4 S .38 A76	868835	2:44		3:01	26.41	439.37	<1:00

E-Ticketing	Date: 07/06/2018							
Truck Number	Mix Design	Ticket Number	Time Batched	Time on Site	Time Dumped	Net Ticket Tons	Cumulative Tons	Approx. Time to Acuqire Data (mins)
H94	CL4 S .38 A76	868973	22:20		22:43	25.58	439.32	3:00
H94	CL4 S .38 A76	868973	22:20		-	25.58	439.32	<1:00
CB25	CL4 S .38 A76	868996	23:05		0:12	25.71	689.85	3:27
CB25	CL4 S .38 A76	868996	23:05		-	25.71	689.85	<1:00
RH3	CL4 S .38 A76	869019	0:31		0:46	25.28	76.69	4:00
RH3	CL4 S .38 A76	869019	0:31		-	25.28	76.69	<1:00
RH2	CL4 S .38 A76	869020	0:36		0:51	25.16	101.85	3:00
RH2	CL4 S .38 A76	869020	0:36		-	25.16	101.85	<1:00
H87	CL4 S .38 A76	869030	1:00		1:35	25.57	257.03	3:00
H87	CL4 S .38 A76	869030	1:00		-	25.57	257.03	<1:00
RR57	CL4 S .38 A76	869071	2:40		2:53	25.97	727.08	3:00
RR57	CL4 S .38 A76	869071	2:40		2:54	25.97	727.08	<1:00
RH2	CL4 S .38 A76	869045	1:36		2:08	24.98	495.21	3:00
RH2	CL4 S .38 A76	869045	1:36		-	24.94	495.21	<1:00
PT155	CL4 S .38 A76	869050	1:54		2:14	26.33	521.54	3:00
PT155	CL4 S .38 A76	869050	1:54		2:15	26.33	521.54	<1:00
PR08	CL4 S .38 A76	869052	2:00		2:19	26.05	547.59	3:00
PR08	CL4 S .38 A76	869052	2:00		2:20	26.05	547.59	<1:00
H98	CL4 S .38 A76	869053	2:04		2:22	25.04	572.63	3:00
H98	CL4 S .38 A76	869053	2:04		2:23	25.04	572.63	<1:00
PR10	CL4 S .38 A76	869056	2:08		2:27	25.99	598.62	3:00
PR10	CL4 S .38 A76	869056	2:08		-	25.99	598.62	<1:00
CB25	CL4 S .38 A76	869060	2:14		2:32	25.83	624.45	3:00
CB25	CL4 S .38 A76	869060	2:14		-	25.83	624.45	<1:00
H87	CL4 S .38 A76	869063	2:21		2:37	25.55	650.00	2:00
H87	CL4 S .38 A76	869063	2:21		-	25.55	650.00	<1:00
H93	CL4 S .38 A76	869064	2:28		2:43	25.89	675.89	3:00
H93	CL4 S .38 A76	869094	2:28		2:44	25.89	675.89	<1:00
H99	CL4 S .38 A76	869068	2:35		2:47	25.22	701.11	2:00
H99	CL4 S .38 A76	869068	2:35		2:48	25.22	701.11	<1:00
PT155	CL4 S .38 A76	869083	3:05		3:24	26.29	856.55	3:00
PT155	CL4 S .38 A76	869083	3:05		3:25	26.69	856.55	<1:00
RH2	CL4 S .38 A76	869084	3:08		3:28	24.84	881.39	2:00
RH2	CL4 S .38 A76	869084	3:08		-	24.84	881.39	<1:00
H98	CL4 S .38 A76	869086	3:14		3:37	25.13	906.52	2:48
H98	CL4 S .38 A76	869086	3:14		3:38	25.13	906.52	<1:00
PR10	CL4 S .38 A76	869087	3:23		3:45	26.08	932.60	3:44
PR10	CL4 S .38 A76	869087	3:23		-	26.08	932.60	<1:00

E-Ticketing	Date: 07/09/2018								
Data	Truck Number	Mix Design	Ticket Number	Time Batched	Time on Site	Time Dumped	Net Ticket Tons	Cumulative Tons	Approx. Time to Acuqire Data (mins)
Conventional	H18	CL2 S.38 B64	869259	10:13		11:21	26.59	495.76	3:00
Technology	H18	CL2 S.38 B64	869259	10:13		-	26.59	495.76	<1:00
Conventional	H62	CL2 S.38 B64	869263	10:41		11:28	25.80	521.56	2:00
Technology	H62	CL2 S.38 B64	869263	10:21		-	25.80	521.56	<1:00
Conventional	H93	CL2 S.38 B64	869264	10:48		11:52	25.99	547.55	3:00
Technology	H93	CL2 S.38 B64	869264	10:48		-	25.99	547.55	<1:00
Conventional	H96	CL2 S.38 B64	869268	11:05		12:04	25.23	572.78	4:33
Technology	H96	CL2 S.38 B64	869268	11:05		-	25.23	572.78	<1:00
Conventional	PR04	CL2 S.38 B64	869271	11:40		12:05	25.90	598.68	4:00
Technology	PR04	CL2 S.38 B64	869271	11:40		-	25.9	598.68	<1:00
Conventional	CB13	CL2 S.38 B64	869272	11:50		12:26	25.38	624.06	4:00
Technology	CB13	CL2 S.38 B64	869272	11:50		-	25.38	624.06	<1:00
Conventional	H79	CL2 S.38 B64	869273	11:56		12:33	26.27	650.33	3:00
Technology	H79	CL2 S.38 B64	869273	11:56		-	26.27	650.33	<1:00
Conventional	H18	CL2 S.38 B64	869274	12:04		-	25.65	675.98	3:00
Technology	H18	CL2 S.38 B64	869274	12:04		-	25.65	674.98	<1:00
Conventional	H74	CL2 S.38 B64	869274	12:13		12:45	26.97	702.95	3:00
Technology	H74	CL2 S.38 B64	869274	12:13		-	26.97	702.95	<1:00
Conventional	H62	CL2 S.38 B64	869277	12:20		12:51	26.05	729.00	3:00
Technology	H62	CL2 S.38 B64	869277	12:20		-	26.05	729.00	<1:00
Conventional	H93	CL2 S.38 B64	869284	12:46		1:07	26.16	755.16	4:00
Technology	H93	CL2 S.38 B64	869284	12:46		-	26.16	755.16	<1:00
Conventional	H96	CL2 S.38 B64	869285	12:54		1:23	25.35	780.81	3:00
Technology	H96	CL2 S.38 B64	869285	12:54		-	25.35	780.51	<1:00

Paired Samples T-Test Data					
Sample No.	Theoretical Tons	Relative Qty Shipped (Tons)	Sample No.	Theoretical Tons	Relative Qty Shipped (Tons)
1	38.432	50.800	39	312.276	309.660
2	60.557	76.010	40	51.038	51.730
3	90.052	102.050	41	83.122	77.660
4	105.229	127.260	42	39.859	25.870
5	133.989	152.420	43	62.358	51.230
6	181.841	178.300	44	144.365	128.940
7	183.285	204.150	45	166.126	154.150
8	257.566	279.020	46	212.568	180.570
9	271.889	304.940	47	245.694	231.780
10	306.985	330.230	48	297.775	283.450
11	323.861	355.450	49	321.251	309.360
12	345.792	381.600	50	372.720	361.390
13	424.066	457.960	51	439.531	413.180
14	434.007	483.170	52	35.672	25.230
15	465.694	509.220	53	143.830	155.560
16	490.442	534.450	54	166.140	181.710
17	598.209	611.150	55	249.292	232.660
18	623.784	636.180	56	271.378	257.400
19	654.566	661.480	57	288.358	309.530
20	714.363	712.710	58	360.906	387.750
21	782.872	738.600	59	22.172	25.360
22	793.134	789.260	60	107.215	102.120
23	48.259	50.230	61	139.205	127.190
24	96.625	101.510	62	271.847	256.270
25	128.070	127.580	63	388.336	359.440
26	182.780	178.480	64	412.983	384.700
27	197.295	204.450	65	515.830	495.490
28	229.034	229.420	66	531.740	521.540
29	244.224	254.750	67	553.056	546.580
30	288.988	305.980	68	677.833	649.840
31	336.339	332.010	69	688.237	675.060
32	378.168	382.960	70	712.433	701.030
33	409.869	408.970	71	738.408	726.390
34	486.757	433.960	72	825.712	777.950
35	18.643	25.880	73	835.692	830.500
36	44.545	52.010	74	878.569	880.470
37	94.838	129.930	75	939.799	933.010
38	277.794	283.170			

t-Test Results		
t-Test: Paired Two Sample for Means	*Relative Qty Shipped (Tons)*	*Theoretical Tons*
Mean	337.326	336.615567
Variance	56986.65892	58922.70724
Observations	75	75
Pearson Correlation	0.99640293	
Hypothesized Mean Difference	0	
df	74	
t Stat	0.295655999	
P(T<=t) one-tail	0.384160421	
t Critical one-tail	1.665706893	
P(T<=t) two-tail	0.768320843	
t Critical two-tail	1.992543495	

APPENDIX 3. PAVE-IR DATA

Pave IR	7/2/2018							
Method	**Latitude**	**Longitude**	**Temp in Hopper (°F)**	**Temp at Screed (°F)**	**Mat Temp RT (°F)**	**Mat Temp CNT (°F)**	**Mat Temp LT (°F)**	**Average Temp (°F)**
Conventional	38.043	-84.567	284.6	310	293	296	303	297.33
Technology	38.043	-84.566	N/A	N/A	294	303	302	299.67
Conventional	38.0417	-84.567	319.8	303	283	292	295	290.00
Technology	38.042	-84.567	N/A	N/A	287	300	298.8	295.27
Conventional	38.0396	-84.568	291	290	285	296	298	293.00
Technology	38.04	-84.57	N/A	N/A	294	309	286	296.33
Conventional	38.0338	-84.5663	264	290	291	301	304	298.67
Technology	38.034	-84.566	N/A	N/A	289	308	298	298.33
Conventional	38.0322	-84.5647	300	281	294	301	309	301.33
Technology	38.0322	-84.564	N/A	N/A	315	316	315	315.33
Conventional	38.0313	-84.5641	286	302	301	305	314	306.67
Technology	38.0313	-84.5642	N/A	N/A	304	304	306	304.67
Conventional	38.0253	-84.558	265	280	299	291	299	296.33
Technology	38.0253	-84.558	N/A	N/A	303	306	309	306.00
Conventional	38.024	-84.5562	312	320	294	307	310	303.67
Technology	38.024	-84.553	N/A	N/A	315	319	301	311.67
Conventional	38.0228	-84.5546	292	308	297	310	318	308.33
Technology	38.0228	-84.5546	N/A	N/A	323	325	325	324.33
Conventional	38.0206	-84.5529	291	290	283	295	301	293.00
Technology	38.0206	-84.553	N/A	N/A	306	308	308	307.33

Pave IR	7/5/2018								
Method	**Latitude**	**Longitude**	**Temp in Hopper (°F)**	**Temp at Screed (°F)**	**Mat Temp RT (°F)**	**Mat Temp CNT (°F)**	**Mat Temp LT (°F)**	**Average Temp (°F)**	**Percent Difference (%)**
Conventional	38.0051	-84.5459	295	306	288	289	286	287.67	
Technology	38.0085	-84.5457	N/A	N/A	286	296	303	295.00	2.49
Conventional	38.0064	-84.547	301	323	317	308	291	305.33	
Technology	38.00644	-84.547	N/A	N/A	308	320	305	311.00	1.82
Conventional	38.009	-84.5491	296	312	302	294	290	295.33	
Technology	38.0091	-84.5491	N/A	N/A	301	299	296	298.67	1.12
Conventional	38.01	-84.5496	294	308	301	292	284	292.33	
Technology	38.01	-84.4496	N/A	N/A	290	308	297	298.33	2.01
Conventional	38.0114	-84.5499	308	295	295	285	277	285.67	
Technology	38.01139	-84.54988	N/A	N/A	295	301	299	298.33	4.25
Conventional	38.0233	-84.555	299	289	302	296	290	296.00	
Technology	38.0233	-84.555	N/A	N/A	296	312	305	304.33	2.74
Conventional	38.0251	-84.5577	312	304	305	300	293	299.33	
Technology	38.025	-84.5576	N/A	N/A	295	314	292	300.33	0.33
Conventional	38.0268	-84.5596	293	320	299	306	293	299.33	
Technology	38.0268	-84.5597	N/A	N/A	288	315	286	296.33	1.01
Conventional	38.029	-84.5619	302	303	300	297	293	296.67	
Technology	38.029	-84.56199	N/A	N/A	270	319	316	301.67	1.66
Conventional	38.0302	-84.563	289	301	311	308	302	307.00	
Technology	38.0302	-84.56297	N/A	N/A	323	321	320	321.33	4.46
Conventional	38.0317	-84.5642	266	297	287	285	276	282.67	
Technology	38.0317	-84.5642	N/A	N/A	293	295	261	283.00	0.12
Conventional	38.032	-84.5645	299	271	295	291	280	288.67	
Technology	38.032	-84.5645	N/A	N/A	278	305	271	284.67	1.41
Conventional	38.0338	-84.566	300	316	307	301	296	301.33	
Technology	38.0338	-84.566	N/A	N/A	314	310	310	311.33	3.21
Conventional	38.0345	-84.5666	298	312	301	296	283	293.33	
Technology	38.0345	-84.5666	N/A	N/A	303	303	274	293.33	0.00

Pave IR	7/6/2018								
Method	**Latitude**	**Longitude**	**Temp in Hopper (°F)**	**Temp at Screed (°F)**	**Mat Temp RT (°F)**	**Mat Temp CNT (°F)**	**Mat Temp LT (°F)**	**Average Temp (°F)**	**Percent Difference (%)**
Conventional	38.0393	-84.568	295	310	301	292	278	290.333	
Technology	38.0394	-84.568	N/A	N/A	297	292	283	290.667	0.11
Conventional	38.0402	-84.568	297	288	289	284	277	283.333	
Technology	38.0402	-84.5678	N/A	N/A	298	299	284	293.667	3.52
Conventional	38.0426	-84.5666	302	300	292	285	276	284.333	
Technology	38.0426	-84.5668	N/A	N/A	294	298	282	291.333	2.40
Conventional	38.0456	-84.5656	273	300	294	287	274	285.000	
Technology	38.0453	-84.5656	N/A	N/A	294	299	297	296.667	3.93
Conventional	38.0389	-84.5681	287	298	301	287	286	291.333	
Technology	38.0347	-84.5682	N/A	N/A	297	294	286	292.333	0.34
Conventional	38.0365	-84.5679	301	310	303	297	285	295.000	
Technology	38.0365	-84.5679	N/A	N/A	300	305	295	300.000	1.67
Conventional	38.0349	-84.5673	281	294	279	280	271	276.667	[redacted]
Technology	[redacted]								
Conventional	38.0291	-84.5624	302	325	314	306	299	306.333	
Technology	38.029	-84.5625	N/A	N/A	312	306	296	304.667	0.55
Conventional	38.0246	-84.5573	278	305	295	287	273	285.000	
Technology	38.0247	-84.5573	N/A	N/A	280	307	299	295.333	3.50
Conventional	38.0236	-84.5559	285	297	286	289	281	285.333	
Technology	38.0236	-84.5558	N/A	N/A	272	278	283	277.667	2.76
Conventional	38.0231	-84.5551	300	305	292	292	285	289.667	
Technology	38.0229	-84.555	N/A	N/A	292	292	294	292.667	1.03
Conventional	38.0225	-84.5545	296	300	291	283	271	281.667	
Technology	38.0226	-884.5545	N/A	N/A	294	303	276	291.000	3.21
Conventional	38.0197	-84.5526	281	297	287	276	270	277.667	
Technology	38.0196	-84.5525	N/A	N/A	288	287	286	287.000	3.25

Paired Samples T-Test Data		
Sample No.	Infrared Gun Temperatures (^{o}F)	Pave-IR Temperatures (^{o}F)
1	297.33	299.67
2	290.00	295.27
3	293.00	296.33
4	298.67	298.33
5	301.33	315.33
6	306.67	304.67
7	296.33	306.00
8	303.67	311.67
9	308.33	324.33
10	293.00	307.33
11	287.67	295.00
12	305.33	311.00
13	295.33	298.67
14	292.33	298.33
15	285.67	298.33
16	296.00	304.33
17	299.33	300.33
18	299.33	296.33
19	296.67	301.67
20	307.00	321.33
21	282.67	283.00
22	288.67	284.67
23	301.33	311.33
24	293.33	293.33
25	290.33	290.67
26	283.33	293.67
27	284.33	291.33
28	285.00	296.67
29	291.33	292.33
30	295.00	300.00
31	306.33	304.67
32	285.00	295.33
33	285.33	277.67
34	289.67	292.67
35	281.67	291.00
36	277.67	287.00

t-Test Results		
t-Test: Paired Two Sample for Means	*Pave-IR*	*Infrared Gun*
Mean	299.1555556	293.7222222
Variance	101.3384127	66.08571429
Observations	36	36
Pearson Correlation	0.815280263	
Hypothesized Mean Difference	0	
df	35	
t Stat	5.591950444	
P(T<=t) one-tail	1.33264E-06	
t Critical one-tail	1.689572458	
P(T<=t) two-tail	2.66528E-06	
t Critical two-tail	2.030107928	

APPENDIX 4: SPECIAL NOTES

SPECIAL NOTE FOR HMA ELECTRONIC DELIVERY MANAGEMENT SYSTEM

(HMA e-Ticketing)

This Special Note will apply when indicated on the plans or in the proposal. Section references herein are to the Department's Standard Specifications for Road and Bridge Construction current edition.

1.0 DESCRIPTION. Incorporate a GPS Fleet Management System for all HMA delivered to the project in order to monitor, track, and report loads of HMA during the construction processes from the point of measurement and loading to the point of incorporation to the project.

2.0 MATERIALS AND EQUIPMENT. Submit to the Engineer for approval, no fewer than 30 days prior to HMA placement activities, a GPS fleet management system supplier that can provide a qualified representative for on-site technical assistance during the initial setup, pre-construction verifications, and data management and processing as needed during the Project to maintain equipment.

Provide operator settings, user manuals, training videos, and required viewing/export software for review. Provide equipment that will meet the following:

1. A wireless fleet management or GPS device that is capable of tracking all delivery trucks (both company-owned and third-party) must be installed on all trucks and equipment (dump trucks, belly dumps, side-load dumps, transfer vehicles, pavers, or any other trucks/vehicles) used to transfer and incorporate HMA into the project. KYTC personnel shall have the ability to access Real Time monitoring through the use of a mobile device such as an iPad, smartphone, etc.

2. The fleet management system shall be fully integrated with the Contractor's Load Read-Out scale system at the HMA plant site.

3. The fleet management system shall have the ability to measure and track vehicles and their contents (weights and material types) continuously from the plant site to the project site. The system shall have internal battery backup capabilities due to loss of power, and have the ability to store data if GPS connectivity is lost and transmit that same data when unit re-establishes connectivity. To be considered continuous, no two data points shall be more than 60 seconds apart unless the vehicle is stopped. Duration of stop time for any reason shall be recorded. The fleet management system shall have the ability to track the engagement of the truck PTO to indicate the dump the material.

3.0 CONSTRUCTION. Provide the Engineer with the manufacturer's specifications and all required documentation for data access at the pre-construction conference.

A. Construction Requirements

1. Install and operate equipment in accordance with the manufacturer's specifications.

2. Verify the GPS is working within the requirements of this Special Note.

B. Data Deliverables

Provide to the Engineer a means in which to gather report summaries by way of iOS apps, web pages, or any other method at the disposal of the Engineer. The Engineer may request data at any time during paving operations.

1. Real-time Continuous Data Items

Provide the Engineer access to a GIS map-based data viewer which displays the following information in real-time with a web-based system compatible with iOS and Windows environments.

- Each Truck
  - UniqueTruck ID
  - Truck status
    - Time At Source
    - Time At Destination
    - Time At Paver
    - Time At Scale
    - Time to and from plant/job
    - Time of PTO engagement
    - Time Stopped with Engine Running
  - Time of last transmission
  - Location (Latitude and Longitude in decimal degrees to nearest 0.0000001) every 60 seconds
  - Description of Material being transported (i.e. asphalt base, asphalt surface)
  - Mix Design Number
  - Net Weight of material being transported to the nearest 0.01 ton
  - Running Daily Total of Net Weight of material being transported to nearest 0.01 ton.
  - Project Number

- Scale Location
- Project Location
- Point of Delivery (i.e. paver)

2. Daily Summary

The following summary information shall be provided to the Engineer electronically within 4 hours of beginning operations on the next working day

- For each Material
  - List of Individual Loads
    - Contractor Name
    - Project Number
    - Unique Truck ID
    - Net Weight For Payment (nearest 0.01 tons)
    - Date
    - Mix Temperature at Time of Loading, Fahrenheit
    - Time Loaded
    - Time Unloaded
    - Delivery Location (Latitude/Longitude in decimal degrees to nearest 0.0000001)
- For each Bid Item
  - Total Quantity for Payment (nearest 0.01 tons)

4.0 MEASUREMENT. The Department will measure the HMA electronic delivery management system as a lump sum item.

5.0 PAYMENT. The Department will make payment for the completed and accepted quantities under the following:

1. Payment is full compensation for all work associated with providing all required equipment, training, and documentation.

2. Delays due to GPS satellite reception of signals or equipment breakdowns will not be considered justification for contract modifications or contract extensions.
3. Payment will be full compensation for costs related to providing the GPS system, including all equipped pavers and transfer vehicles, integration with plant load-out systems, and any software required for the construction and reporting process. All quality control procedures including the GPS systems representative's technical support and on-site training shall be included in the Contract lump sum price.

Code	Pay Item	Pay Unit
	HMA ELECTRONIC DELIVERY MANAGEMENT SYSTEM	EACH

SPECIAL NOTE FOR PAVER MOUNTED TEMPERATURE PROFILES

This Special Note will apply when indicated on the plans or in the proposal. Section references herein are to the Department's Standard Specifications for Road and Bridge Construction current edition.

1.0 DESCRIPTION. Provide paver mounted infrared temperature equipment to continually monitor the temperature of the asphalt mat immediately behind all paver(s) during the placement operations for all driving lanes (including ramps for Interstates and Parkways) within the project limits. Provide thermal profiles that include material temperature and measurement locations. Provide equipment measuring material temperature within the paver hopper and at the vibratory screed.

2.0 MATERIALS AND EQUIPMENT. In addition to the equipment specified in Subsection 403.02 utilize a thermal equipment supplier that can provide a qualified representative for onsite technical assistance during the initial setup, pre-construction verification, and data management and processing as needed during the project to maintain equipment within specifications and requirements.

Provide operator settings, user manuals, required viewing/export software for analysis. Ensure the temperature equipment will meet the following:

1. A device with one or more infrared sensors that is capable of measuring in at least 1 foot intervals across the paving width, with a minimum width of 12 feet, or extending to the recording limits of the equipment, whichever is greater. A Maximum of two (2) brackets are allowed in the influence area under the sensors. A temperature profile must be made on at least 1 foot intervals longitudinally down the road;
2. Infrared sensor(s):
    - Measuring from 32°F to 400°F with an accuracy of ± 2.0% of the sensor reading;
3. Ability to measure the following:
    - The placement distance using a Global Positioning System (GPS) or a Distance Measuring Instrument (DMI) and a Global Positioning System (GPS)
    - Stationing;
4. GPS: Accuracy ± 4 feet in the X and Y Direction;
5. Latest version of software to collect, display, retain and analyze the mat temperature readings during placement. The software must have the ability to create and analyze:
    - Full collected width of the thermal profiles,
    - Paver speed and
    - Paver stops and duration for the entire Project;
6. Ability to export data automatically to a remote data server;

At the preconstruction meeting, provide the Department with rights to allow for web access to the data server. This web-based software must also provide the Department with the ability to download the raw files and software and to convert them into the correct format.

The thermal profile data files must provide the following data in a neat easy to read table format:

- Project information including Road Name and Number, PCN, Beginning and Ending MPs.
- IR Bar Manufacturer and Model number
- Number of Temperature Sensors (N)
- Spacing between sensors and height of sensors above the asphalt mat
- Total number of individual records taken each day (DATA BLOCK)
- Date and Time reading taken
- Latitude and Longitude
- Distance paver has moved from last test location
- Direction and speed of the paver

3.0 CONSTRUCTION. Provide the Engineer with all required documentation at the pre-construction conference.

1. Install and operate equipment in accordance with the manufacturer's specifications.
2. Verify that the temperature sensors are within ± 2.0% using an independent temperature device on a material of known temperature. Collect and compare the GPS coordinates from the equipment with an independent measuring device.
   - Ensure the independent survey grade GPS measurement device is calibrated to the correct coordinate system (using a control point), prior to using these coordinates to validate the equipment GPS.
   - The comparison is considered acceptable if the coordinates are within 4 feet of each other in the X and Y direction.
3. Collect thermal profiles on all Driving Lanes during the paving operation and transfer the data to the "cloud" network or if automatic data transmission is not available, transfer the data to the Engineer at the end of daily paving.
4. Contact the Department immediately when System Failure occurs. Daily Percent Coverage will be considered zero when the repairs are not completed within two (2) working days of System Failure. The start of this two (2) working day period begins the next working day after System Failure.
5. Evaluate thermal profile segments, every 150 feet, and summarize the segregation of temperature results. Results are to be labeled as Minimal 0°-25°F, Moderate 25.1°-50°F and Severe >50°. Severe readings over 3 consecutive segments or over 4 or more segments in a day warrant investigation on the cause of the differential temperature distribution.

4.0 MEASUREMENT. The Department will measure the total area of the driving lanes mapped by the infrared scanners. Full payment will be provided for all driving lanes with greater than 85% coverage. Partial payment will be made for all areas covered from 50% coverage to 85% coverage at the following rate Coverage area percentage X Total bid amount. Area with less than 50% coverage will not be measured for payment.

5.0 PAYMENT. The Department will make payment for the completed and accepted quantities under the following:

1. Payment is full compensation for all work associated with providing all required equipment, training, and documentation.
2. Delays due to GPS satellite reception of signals or equipment breakdowns will not be considered justification for contract modifications or contract extensions.

Code	Pay Item	Pay Unit
24891EC	PAVE MOUNT INFRARED TEMP EQUIPMENT	SQFT

SPECIAL NOTE FOR INTELLIGENT COMPACTION OF ASPHALT MIXTURES

This Special Note will apply when indicated on the plans or in the proposal. Section references herein are to the Department's Standard Specifications for Road and Bridge Construction current edition.

1.0 DESCRIPTION. Provide and use Intelligent Compaction (IC) Rollers for compaction of all asphalt mixtures.

2.0 MATERIALS AND EQUIPMENT. In addition to the equipment specified in Subsection 403.02, a minimum of one (1) IC roller is to be used on the project at all times. The Contractor may elect to only use one (1) IC roller for compaction, but two (2) IC rollers are preferred as any combination of the breakdown, intermediate and finish rollers in the roller train. All IC rollers will meet the following minimum characteristics:

1) Are self-propelled double-drum vibratory rollers equipped with accelerometers mounted in or about the drum to measure the interactions between the rollers and compacted materials in order to evaluate the applied compactive effort. The IC rollers must have the approval of the Engineer prior to use. Examples of rollers equipped with IC technology can be found at www.IntelligentCompaction.com.

2) Are equipped with non-contact temperature sensors for measuring pavement surface temperatures.

3) The output from the roller is designated as the IC-MV which represents the stiffness of the materials based on the vibration of the roller drums and the resulting response from the underlying materials.

4) Are equipped with integrated on-board documentation systems that are capable of displaying real-time color-coded maps of IC measurement values including the stiffness response values, location of the roller, number of roller passes, machine settings, together with the material temperature, speed and the frequency and amplitude of roller drums. Ensure the display unit is capable of transferring the data by means of a USB port or through wireless transmission.

5) Are equipped with a mounted Global Positioning System GPS radio and receiver either a Real Time Kinematic (RTK-GPS) or Global Navigational Satellite System (GNSS) units that monitor the location and track the number of passes of the rollers. Accuracy of the positioning system is to be a minimum of 12 inches.

3.0 WORK PLAN. Submit to the Engineer an IC Work Plan at the Preconstruction Conference and at least 2 weeks prior to the beginning of construction. Describe in the work plan the following:

1. Compaction equipment to be used including:
    - Vendor(s)
    - Roller model(s),
    - Roller dimensions and weights,
    - Description of IC measurement system,
    - GPS capabilities
    - Documentation system,
    - Temperature measurement system, and
    - Software.

2. Roller data collection methods including sampling rates and intervals and data file types.

3. Transfer of data to the Engineer including method, timing, and personnel responsible. Data transfer shall occur at minimum twice per day or as directed by the Engineer and is to be electronic.

4. Training plan and schedule for roller operators, project foreman, project surveyors, quality control technicians, and Cabinet personnel including project engineers and field inspectors; including both classroom and field training. Training should be conducted at least 1 week before beginning IC construction. The training is to be performed by a qualified representative(s) from the IC Roller manufacture(s) to be used on the project. The training should be 4-8 hours in duration and minimum training topics shall include:

1. Background information for the specific IC system(s) to be used

2. Setup and checks for IC system(s), GPS receiver, base-station and hand held rovers

3. Operation of the IC system(s) on the roller; i.e., setup data collection, start/stop of data recording, and on-board display options

4. Transferring raw IC data from the rollers(s)

5. Operation of vendor's software to open and view raw IC data files and exporting all-passes and proofing data files in Veda-compatible format

6. Operation of Veda software to import the above exported all-passes and proofing data files, inspection of IC maps, input point test data, perform statistics analysis, and produce reports for project requirements

7. Coverage and uniformity requirements

4.0 CONSTRUCTION. Do not begin work until the Engineer has approved the IC submittals and the IC equipment.

Follow requirements established in Section 400 for production and placement, materials, equipment, acceptance plans and adjustments except as noted or modified in this Specification. Provide the Engineer at least one day's notice prior to beginning construction or prior to resuming production if operations have been temporarily suspended. Ensure paving equipment complies with all requirements specified in Section 400. The IC roller temperatures will be evaluated by the Department with the data from a Paver Mounted Infrared Temperature Gauge.

A. Pre-Construction Test Sections(s) Require

1. Prior to the start of production, ensure the proper setup of the GPS, IC roller(s) and the rover(s) by conducting joint GPS correlation and verification testing between the Contractor, GPS representative and IC roller manufacturer using the same datum.

1. Ensure GPS correlation and verification testing includes the following minimum processes:

   a. Establish the GPS system to be used either one with a base station or one with mobile receivers only. Ensure all components in the system are set to the correct coordinate system; then,

   b. Verify that the roller and rover are working properly and that there is a connection with the base station; then,

c. Record the coordinates of the two edges where the front drum of the roller is in contact with the ground from the on-board, color-coded display; then,

d. Mark the locations of the roller drum edges and move the roller, and place the mobile receiver at each mark and record the readings; then,

2. Compare coordinates between the roller and rover receivers. If the coordinates are within 12.0 in. of each other, the comparison is acceptable. If the coordinates are not within 12.0 in., diagnose and perform necessary corrections and repeat the above steps until verification is acceptable.

3. Do not begin work until acceptable GPS correlation and verification has been obtained.

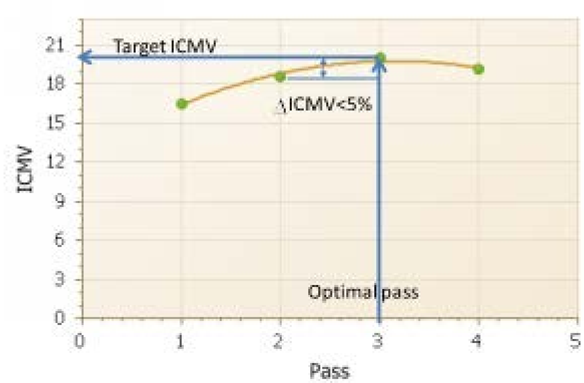
4. The Contractor and the Department should conduct random GPS verification testing during production to ensure data locations are accurate. The recommended rate is once per day with a requirement of at least once per week.

5. All acceptance testing shall be as outlined in Standard Specifications Section 400.

B. Construction Test Section(s) Requirements

Construct test section(s) at location(s) agreed on by the Contractor and the Engineer within the project limits. The test section is required to determine a compaction curve of the asphalt mixtures in relationship to number of roller passes and to the stiffness of mixture while meeting the Department in-place compaction requirements. All rollers and the respective number of passes for each is to be determined via control strip each time a material change, equipment change or when the Engineer deems necessary.

Conduct test section(s) on every lift and every asphalt mixture. Ensure test section quantities 1,000 tons of mainline mixtures. Operate IC rollers in the low to medium amplitude range and at the same settings (speed, frequency) throughout the section while minimizing overlapping of the roller, **the settings are to be used throughout the project with no changes.** After each roller pass, the qualified technician from the contractor observed by the Department will use a nondestructive nuclear gauge that has been calibrated to the mixture to estimate the density of the asphalt at 10 locations uniformly spaced throughout the test section within the width of a single roller pass. The density readings and the number of roller passes needed to achieve the specified compaction will be recorded. The estimated target density will be the peak of the average of the nondestructive readings within the desired compaction temperature range for the mixture. The IC roller data in conjunction with the Veda software will create an IC compaction curve for the mixture. The target IC-MV is the point when the increase in the IC-MV of the material between passes is less than 5 percent on the compaction curve. The IC compaction curve is defined as the relationship between the IC-MV and the roller passes. A compaction curve example is as follows:



Subsequent to the determination of the target IC-MV, compact an adjoining > 250 < 500 tons section using same roller settings and the number of estimated roller passes and allow the Department to verify the compaction with the same calibrated nondestructive nuclear gauge following the final roller pass. The Department will obtain cores at 10 locations, uniformly spaced throughout the test section within the width of the single roller. Obtain GPS measurement of the core locations with a GPS rover. Use the Veda software to perform least square linear regression between the core data and IC-MV in order to correlate the production IC-MV values to the Department specified in-place air voids. A sample linear regression curve example is as follows.

C. Construction Requirements

Use the IC roller on all lifts and types of asphalt within the limits of the project.

During construction, the Quality Control Technician shall be responsible for the following minimum functions:

1. Daily GPS check testing for the IC roller(s) and rover(s).

2. Test section construction to establish target compaction pass counts and target values for the strength of the materials using the standard testing devices; i.e., Nondestructive density gauges, pavement cores, and IC roller(s).

3. Monitoring of the construction operations and the IC roller(s) during production and final evaluation operations.

4. Quality control testing to monitor the pavement temperature and the required level of compaction.

5. Daily download and analysis of the IC data from the roller(s).

6. Daily set-up, take down and secure storage of GPS and IC roller components

Ensure the optimal number of roller passes determined from the test sections has been applied to a minimum coverage of 80% of the individual IC Construction area. Ensure a minimum of 75% of the individual IC Construction area meets the target IC-MV values determined from the test sections.

Do not continue paving operations if IC Construction areas not meeting the IC criteria are produced until they have been investigated by the Department. Obtain the Engineer's approval to resume paving operations. Non-IC rollers are allowed to be used as the third roller on the project; one of the breakdown or the finish rollers is to be equipped with IC technology.

The Contractor shall coordinate for on-site technical assistance from the IC roller representatives during the initial seven (7) days of production and then as needed during the remaining operations. As a minimum, the roller representative shall be present during the initial setup and verification testing of the IC roller(s). The roller representative shall also assist the Contractor with data management using the data analysis software including IC data input and processing.

IC Construction areas are defined as subsections of the project being worked continuously by the Contractor. The magnitude of the IC Construction areas may vary with production but must be at least 750 tons per mixture for evaluation. Partial IC Construction areas of < 750 tons will be included in the previous evaluation. IC Construction areas may extend over multiple days depending on the operations.

The IC Construction Operations Criteria does not after the Department's acceptance processes for the materials or construction operations.

5.0 MEASUREMENT. The Department will measure the total tons of asphalt mixtures compacted using the IC roller(s). Compaction is to be performed by a minimum of one IC roller, material compacted by rollers not equipped with properly functioning IC equipment will not be accepted for payment of the bid item asphalt mixtures IC rolled. Use of non-IC rollers can be accepted on small areas due to equipment malfunctions at the written approval of the Engineer. Paving operations should be suspended for equipment malfunctions that will extend over three days of operation.

6.0 PAYMENT. The Department will make payment for the completed and accepted quantities under the following:

1. Payment is full compensation for all work associated with providing IC equipped rollers, transmission of electronic data files, two copies of IC roller manufacturer software, and training.

2. Delays due to GPS satellite reception of signals to operate the IC equipment or IC roller breakdowns will not be considered justification for contract modifications or contract extensions.

Code	Pay Item	Pay Unit	
24781EC	Intelligent Compaction for Asphalt	TON	May 4, 2015

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