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ADVANCED TECHNOLOGIES FOR EFFICIENT TRANSPORTATION CONSTRUCTION INSPECTION

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ADVANCED TECHNOLOGIES FOR EFFICIENT TRANSPORTATION CONSTRUCTION
INSPECTION

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

Clyde Wesley Newcomer IV

Lexington, Kentucky

Director: Dr. Gabriel Dadi, Department of Civil Engineering, University of Kentucky

Lexington, Kentucky

2018

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ABSTRACT OF THESIS

ADVANCED TECHNOLOGIES FOR EFFICIENT TRANSPORTATION CONSTRUCTION INSPECTION

Collecting load tickets is an example of an antiquated practice that puts inspectors in harm's way either adjacent to traffic, in close proximity to moving or backing equipment, or at times requires climbing onto trucks to reach tickets. Technology exists to collect this information electronically allowing for safer, efficient inspection methods. Departments of Transportation are charged with inspecting an increasing work load with a diminishing number of inspection staff. Recently, doing more with less has led to the prioritization of inspection activities and resulted in less collection of data and visual inspection on projects. Technology advancements are available to improve data collection and provide for more efficient inspection. Using GPS and GIS technology tied into electronic scale report-out systems, a fleet tracking system traces haul routes, reports travel time and tonnage, and even assists contractors with equipment matching and balancing. Data from this system coupled with other technologies remote monitoring of temperature, intelligent compaction, and network enabled cameras provide an opportunity to enhance inspection and increase construction inspection productivity all the while enriching detail of project records. The contribution of this paper is to provide a framework in which to combine these technologies into a multi-faceted, enhanced inspection approach.

KEYWORDS: Remote Sensing, E-Ticketing, Highway Construction, Paver Mounted Thermal Profiler, Intelligent Compaction

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4/13/2018

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INSPECTION

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1. Introduction

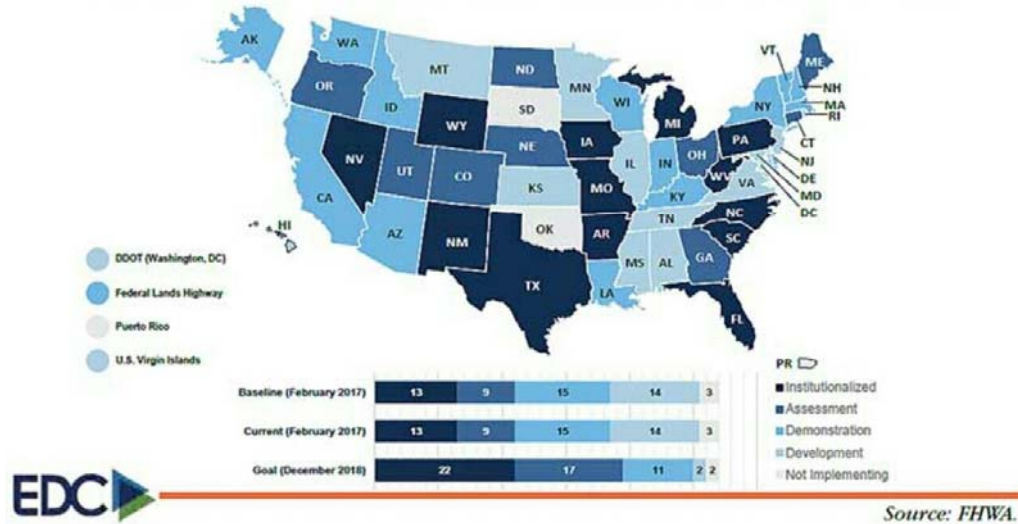
Our rich history of development has taught us to compete, to stand-out, to work hard, and to construct and enhance our creations. Civil Engineers are always looking to implement new ideas, to build stronger structures, and to develop and adopt new technologies to improve construction. In today's society, technology is constantly having to keep up with the fast-pace work environment, communication of personnel, and as engineers are challenged to provide more broad services economically. Mobile devices, computer software, and applications can help achieve data collection, sharing services, real-time updates, the remarkable ability to answer questions at a push of a button, and so much more. So why do the Kentucky Department of Transportation and private contractors need today's technologies? Because we are innovative, we are efficient, we are task-oriented, responsible, and seek solutions to build up our transportation roadways to its fullest potential. Companies not only want to compete in efficiency, but maintain safety, quality, reliability, documentation, and manage deviation. With new roads being built to meet population increases, and rising construction costs, available funding is not adequate to prevent old roads from deteriorating (Walton 2009). E-ticketing, infrared scanning, and intelligent compaction will be evaluated throughout this thesis and used in the field. Consequently, it is believed these technologies will change the outlook of efficient construction inspection and continue to develop throughout the years. The final evaluation will report the applicability of the tested technologies and the benefits and costs of their use on the KYTC projects. In this Thesis,

the discussion of these technologies will potentially have a large impact on how we build roads, communicate, and contribute to the life expectancy of our great designs.

2. Background

This study coordinated with KYTC District 7 to use technology as a complement to typical inspection tasks required of KYTC personnel. The operations that will be under review are asphalt paving and the potential test project would involve a resurfacing project in order to limit the project size and timeline of the study. For simplicity and control of the study, the focus will be solely on the asphalt pavement operations in the field and will exclude plant operations, milling, maintenance of traffic, striping, and other operations typically included in a paving project. In this regard, project inspection is not entirely supplemented, but the goal is to reduce the workload on inspection staff, increase inspector safety, allow for inspection focus on areas that are more experienced based (visual inspection), and augment data collection. The data collection will include: ticket receipt and acceptance; tracking theoretical tonnage of asphalt; temperature monitoring behind the paver, truck bed, and paver hopper; monitoring roller operation; and communicating with contractor QC for nuclear density measurements (refer to Table 9.1). Other states have already adopted some of these technologies, implemented the data collection, and according to the Federal Highway Administration's goal, they want to have 21 states institutionalize e-Construction and 13 States Implement e-Construction and Construction Partnering by the end of 2018 (Figure 2.1).

e-Construction Implementation as of February 2017



Source: FHWA.

Figure 2.1: E-Construction Implementation (Weisner 2017)

3. E-Ticketing

Electronic ticketing, or E-ticketing, is used during the construction phase of projects. In short, this provides agencies with the ability to go paperless. For this study we plan to work alongside EarthWave Technologies Company, using 'fleet watcher,' named to represent the e-ticketing technology. Earth Wave Technologies will help set up this program for our study. Furthermore, they will set up Geo-Fences around the asphalt plant that will detect GPS signals. Figure 3.2 shows the development of a static GeoZone around the perimeter of the plant site, a tighter sub-Geozone established around the scale to zero in on load-out times, and a mobile Geozone of approximately 20-foot radius at the paver (E-ticketing shows promise of speeding process and improving accuracy at asphalt full job sites) (Iowa DOT 2015). GPS trackers will be placed in each truck to notify the team, inspectors, contractors, and personnel when the asphalt trucks arrive and when they leave the jobsite. During this study, we are only using e-ticketing for asphalt, but it can be used in any delivery of materials. Additionally, 'fleet watcher' is also going to work with the "batch plant", to relay additional data to the personnel in the field. In the past, each asphalt truck carried a load ticket. Now, this study will be replacing the load ticket with an e-ticket.

Each e-ticket will have the ticket receipt and acceptance, delivery and dump times, ability to track theoretical tonnage, and track the vehicles and see where they are on the road (Iowa DOT 2016). However, it does not stop there. Earth Wave Technologies will set up a geo fence around the entire project to detect when the truck enters and leaves the project zone, but also set up a smaller geo zone around the actual paver. Specifically, all personnel will know when it is dumping. This is very important because we don't want the trucks waiting on other trucks to finish dumping, which consequently, would slow production. On projects, it is vital to not have back log or wait time. So, this system allows for efficiency and the capability to track the truck queue on the project. The technology itself is just an application that can be installed on other smart-devices. Earth wave constructed the app. Therefore, when you buy the technology you have unlimited access to the entire e-ticket. With this technology the inspector will be able to multitask. In Figure 3.1, the inspector uses a mobile device to scan the barcode on the stockpile pipe. After accessing the electronic delivery ticket for the material, she can link the e-ticket and the photos she shoots using the tablet to her daily report for measurement and payment (Weisner 2017).



Figure 3.1: E-Ticketing on a Mobile Device (Weisner 2017)

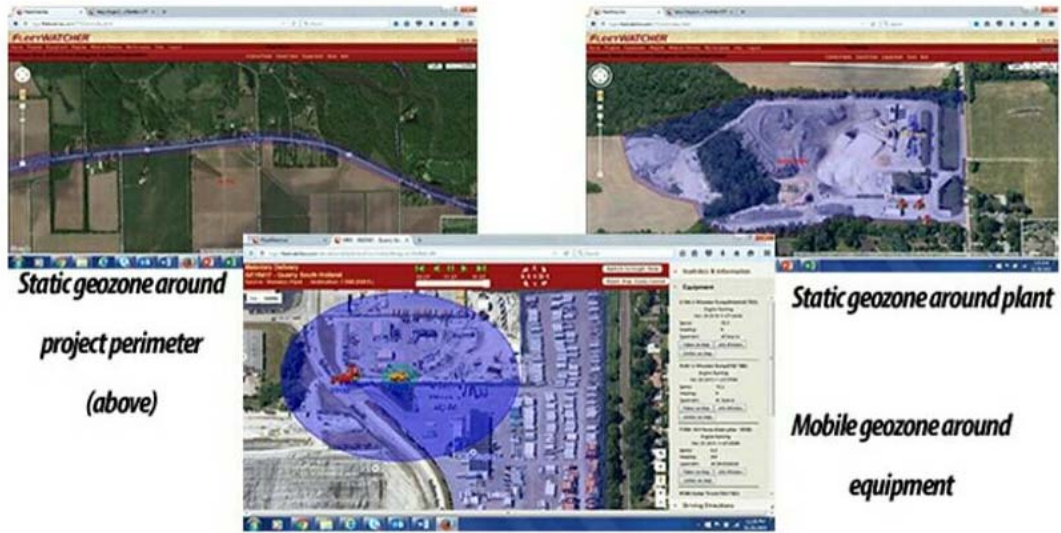


Figure 3.2: Earthwave Geozone Example (Iowa DOT 2015)

4. Paver Mounted Thermal Profiler

This technology is an infrared scanner that is placed on the back of a paver. Once utilized, the technology uses infrared sensors to create a live thermal profile of the asphalt mat. While using this infrared technology, inspectors will be able to view temperatures across the mat at any station they desire. Infrared scans will identify any cold spots or streaks in the mat which directly relate to lower density sections (FHWA 2018). Furthermore, density segregation will significantly impact the pavements lifetime performance and that is why this technology is significant in stopping that process. They have a monitor screen placed on the paver that can show real-time results of the scans, each scan records thermal data of the mat (FHWA 2018). Figure 4.1 shows the equipment that will pick up on thermal real-time visualization for asphalt paving (MOBA 2018). PAVE-IR is the innovative system for process optimization and documentation in road construction (MOBA 2018).

ASPHALT TEMPERATURE MEASUREMENT SYSTEM



Figure 4.1: Smart Paver (MOBA 2018)

Personnel also have the option to place additional sensors on equipment, such as on the compactor, back of the dump trucks, on the screed, in the hopper, and so forth. With this thermal visualization, the construction now has insights into the quality of the material being laid. MOBA Mobile Automation delivers a breakdown of the system's components in which they accurately depict what each component can sustain and deliver to the entire innovative technology shown in Figure 4.2 (MOBA 2018). If there are differences in the material being laid, immediate measures can be taken to correct the road. This technology is also compatible with every paver. There exist three main competences of the infrared scanner, "high-precision data acquisition with innovative cloud solution linked to open interfaces for current asphalt logistics and process systems, as well as a highly scalable reporting system" (MOBA 2018). This combination of the innovative tool accurately depicts measurement to evaluation.



Figure 4.2: MOBA System Components (MOBA 2018)

There have been several other DOT's to successfully utilize infrared temperature monitoring on a pilot project including Iowa and Texas. Pave-IR run by MOBA Mobile Automation appear to be the only company competing in the field of providing temperatures across the asphalt mat in real time on a monitor displayed onboard the paver. This entire system would cost roughly \$34K for each pavement operation or \$18K to rent the equipment for a 2 month project. The price for a rental of the equipment covers a \$3,000 installation charge, plus an additional \$7,500 charge per month of rental (Appendix A). Devices such as a Microsoft Tablet will allow an inspector to see the pavement data given, Java, Adobe, and MOBA Pave Project have been installed on the device. This will allow for data transmission as close to real time as possible. Eventually with the help of this equipment among others being implemented in this project, technicians will be able to monitor and inspect resurfacing projects without having to be on site. Allowing them to become more efficient and able to inspect multiple projects simultaneously (MOBA 2018).

5. Intelligent Compaction

“Intelligent Compaction (IC) refers to the compaction of road materials, such as soils, aggregate bases, or asphalt pavement materials, using modern vibratory rollers equipped with an integrated measurement system, an onboard computer reporting system, Global Positioning System (GPS) based mapping, and optional feedback control. IC rollers facilitate real-time compaction monitoring and timely adjustments to the compaction process by integrating measurement, documentation, and control systems. IC rollers also maintain a continuous record of color-coded plots, allowing the user to view plots of the precise location of the roller, the number of roller passes, and material stiffness measurements” (*How Can I Implement Intelligent Compaction?* 2018).

Intelligent Compaction can tell the driver where on the mat they need to go from the smart technology of its sensors. This tool uses a GPS to predict location and know where to go on the road. The compactor will know when to make a pass. This is relevant because the compactor does not want to miss any section of the road. The personnel driving the compactor would only need to follow the monitor. The screen will let them know where they need to go and what they need to pass again to cover the entire road. Presentation by Don Matthews on Intelligent Compaction for the CalAPA Spring Asphalt Pavement Conference & Equipment Expo on the automated machine guidance roller w/ retrofit system is presented in Figure 5.1 (Matthews 2015). The instrumentation of this technology says, “to determine the effectiveness of the compaction process, compaction meters or accelerometers are mounted in or about the drum to monitor applied compaction effort, frequency, and response from the material being compacted” (*How Can I Implement Intelligent Compaction?* 2018). It is necessary for this technology to ensure roads have quality and long-lasting performance. In Figure 5.2 a Technical Brief by the U.S. Department of Transportation Federal Highway Administrative identifies the factors that affect ICMV (FHWA 2017).



Figure 5.1: Intelligent Compaction (Matthews 2015)

FACTORS THAT AFFECT ICMV

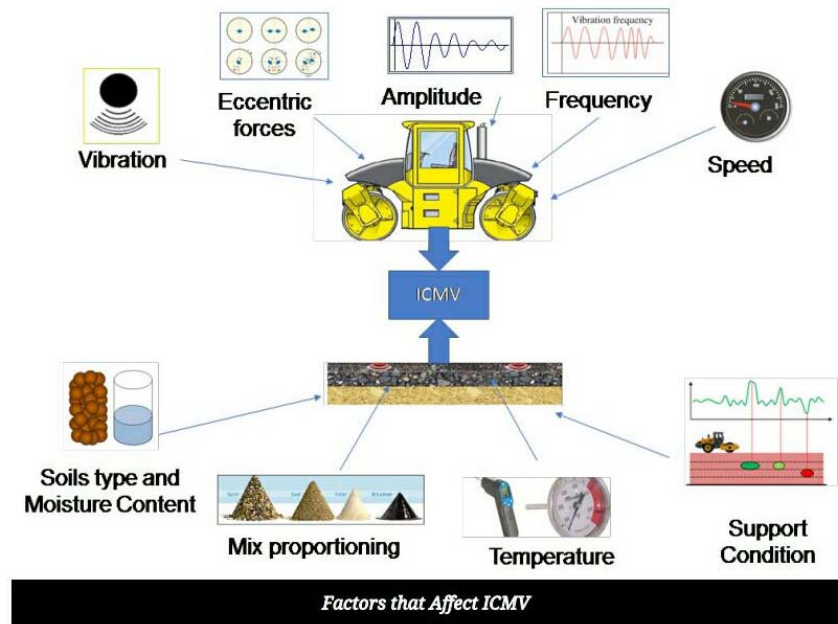


Figure 5.2: ICMV Factors (FHWA 2017)

6. Results

6.1 Technology 1 – E-Ticketing

E-ticketing has multiple benefits, with time and cost savings from the use of electronic documentation being the priority. The list of benefits is significant:

“Reduction or elimination of paper, operations in a secure environment, ease of document access and searchable text, real-time document access, controlled and improved document distribution and workflow, standardization of reports and forms, reduced storage and less loss of paperwork, enhanced disaster recovery, doing various tasks anywhere with no mobile restrictions, improved cash flow, reduction in claims, field staff on the jobsite for a higher percentage of time, easier access to manuals, plans and project information, faster document approval, ability to sign electronic documents remotely, faster and more accurate payments to contractors, transparency- documents available for viewing by all project partners, integration with other core systems, such as accounting and asset management systems” (Weisner 2017).

As of 2017, there are many offices that have implemented e-ticketing technology into their resources. Table 6.1 shows a chart of the FHWA Division Office technology being used and the amount of devices initiated in 2017 (Weisner 2017). Considerable milestones are taking advancement as Iowa reaches paperless technology, PennDOT goes mobile, as well as Michigan leading the way with their state mandated e-construction initiative (Weisner 2017). Michigan has recorded massive savings along with the effective use of their inspector’s time.

Table 6.1: Technologies Used by DOTs (Weisner 2017)

Technology Used by Each Participating FHWA Division Office			
FHWA Division Office	Device	Number of Devices	Activities
Florida	iPad Air (shared pool/platform)	6	Used routinely on project inspections and program reviews to load electronic inspection forms and for training for shared users.
Iowa	iPad Air (individually assigned)	7	Used routinely on field inspections and compliance assessment program reviews and to access Iowa DOT's document management system.
Michigan	iPad Air (individually assigned and 2 replaced computers)	7	Obtained access to MDOT sites outside FHWA's firewall through a policy exception.
Texas	Surface Pro (3 individually assigned and 3 in shared pool/platform)	6	Not using applications, rather using tablet as the main interface to capture information and data.
Utah	Surface Pro (individually assigned and 2 replaced computers)	4	Laptop replacement with Microsoft Surface Pro. Primary benefit cited as greater mobility as compared to laptop. Microsoft operating system enables uses similar to a laptop but with extra portability.
West Virginia	No devices assigned. Serves as the control for comparison to others.	0	Using laptops and working with the State Division of Highways to implement electronic signatures for change orders and other documents.

Iowa DOT inspectors claimed that, “we have the ability to send out automatic emails and texts when orders are placed, deliveries are loaded, and orders are completed. Customers can sign in and track their trucks to the job” and also communicating the frequent time management this electronic tool saves, “if you’ve ever worked with concrete, you know it hardens over time. There is a window at which the concrete must be poured for it to be acceptable to use on one of our projects. Now the inspector can more closely monitor the timing of deliveries for quality control” (Iowa DOT 2016). Iowa plans to work with their industry partners closely to communicate when they’re material ships, processes, and enters the project.

6.2 Technology 2 – Paver Mounted Thermal Profiler

Utilizing an infrared scanner behind the paver could greatly increase pavement performance and life, by allowing the contractor to fix bad sections immediately, rather than after failure. This method could also increase safety of the paving operation by cutting back the need of the inspector to walk alongside the operation and the need to record the temperature of the pavement inside the truck. With the mapping of temperature contours we are able to evaluate materials by measurement of their surface temperature and its variations. To benefit the life of the road, this technology can prevent cold spots, such as, fatigue cracks, raveling, and potholes (FHWA 2018). Increasing the life of the road directly correlates with the decrease in maintenance costs. Figures 6.1, 6.2, and 6.3 show the US24 Project Report submitted to the Missouri Department of Transportation indicates multiple forms of the IR data analysis which includes paver stops, passes, and temperature profile readings. (FHWA 2018)



Figure 6.1: Thermal Profile of Mat (FHWA 2018)

IR Data Analysis

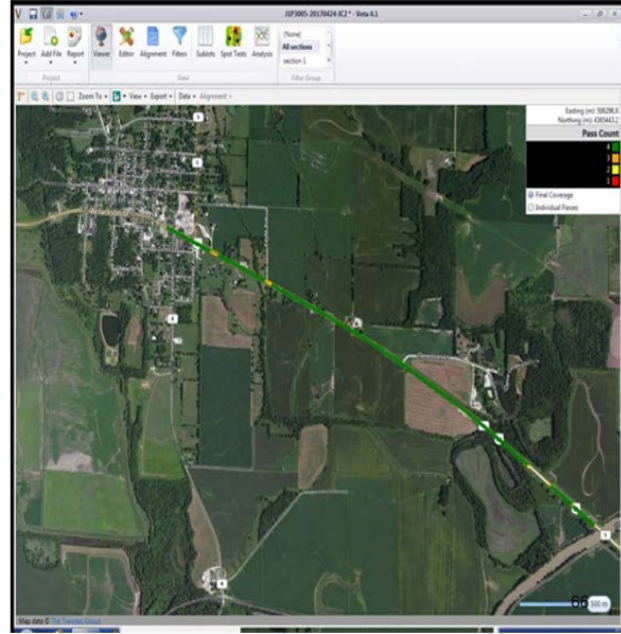
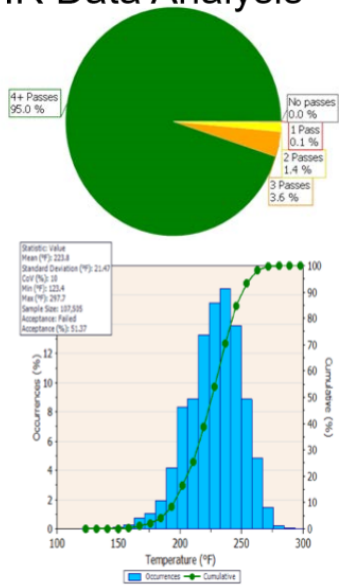


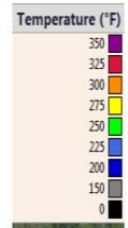
Figure 6.2: IR Data Analysis (FHWA 2018)

IR & Paver Stops

IRI
ALR

IR &
Paver
Stops

IRI
ALR



EB, RT24
2017-04-24

Figure 6.3: IR Expanded Analysis (FHWA 2018)

Data processing and reports will maintain the raw temperature profile of the analysis zone, paving area, and sensor width. There are “three steps to eliminate invalid temperature measurements: 1. Eliminate measurement locations within 2 feet of the mat’s edge, eliminate temperature readings less than 170 Fahrenheit and greater than 400 Fahrenheit, and eliminate data with paver stops greater than 60 Seconds” (FHWA 2018). Studies found by the SHRP2 RO6C that “properly installed and maintained tarps significantly reduced the temperature differentials by about 40%” which could show advantage in our study (FHWA 2018). The feedback that was posted in the webinar by the *SHRP2 RO6C Technology to Enhance Quality Control on Asphalt Pavements* quoted some noteworthy reviews from customers, stating, “the scanner helps in adding trucks for increased uniformity, adjusting practices, and shows the benefits of short hauling; the scanner data is a vivid tool for showing how readability is influenced by the uniformity of temperatures” and “the IR scanner technology saves one grind of a project, the equipment paid for itself; Maine DOT” (FHWA 2018). However, it must be considered for quality thermal readings that the proper equipment is used and purchased. Trucks with good beds, MTV’s with remixing capability, paved automation, and so forth will make the Paver Mounted Thermal Profiler perform adequately.

6.3 Technology 3 – Intelligent Compaction

The major benefits of IC can be categorized within the following areas: Improved Density, “agencies and the public receive a better return on their monetary investment in pavements when their funds can lengthen service lives and reduce maintenance costs;” Increased Productivity, “because IC systems are designed to operate at optimum compactive effort, compaction is more efficient. The result: equivalent or better levels of density in less time and with fewer roller passes than are typically required;” Reduction of Highway Repair Costs, “this enhanced method of achieving uniformly adequate density aims to reduce the occurrence of spot failures and improve the efficiency of compaction operations, thereby lowering costs for paving contractors, State DOTs, and the traveling public;” Continuous Record of Material Stiffness Values, “possible benefits include instant identification of weak areas that need to be reworked or recompacted, the avoidance of harmful overcompaction, and potential use in design or performance specifications through integration with pavement modulus values;” Identification of Non-Compactable Areas, “there are several options: removal and replacement of weak underlying materials, stabilization and recompaction of underlying materials, or modification of the compaction requirements for the specific material. Users now possess the ability to more accurately determine their project’s weak spots and assess their subsequent choices for successful compaction;” and Improved Depth of Compaction, “can increase the maximum amplitude used during initial roller passes. Evaluation of thick aggregate base materials in the U.S. has produced evidence to confirm the usefulness of this feature” (Chang 2011). To further understand

overcompaction, it is defined by the “crushing of aggregate or low air void content, leading to rutting or flushing” (Sommerfeldt 2018). In Figure 6.4, the IC Road Map outlines the most efficient way to begin implementing IC—these strategies will help overcome potential gaps or barriers (*How Can I Implement Intelligent Compaction?* 2018).

Track 1: Equipment and Technologies

- Subtrack 1.1: Standardization of IC roller measurement systems
- Subtrack 1.2: Practical use of GPS in IC
- Subtrack 1.3: Valid in-situ point tests to correlate with IC measurements

Track 2: Data Management and Integration

- Subtrack 2.1: National IC database and data collection guidelines
- Subtrack 2.2: Standardization of IC data storage and exchange
- Subtrack 2.3: A software tool for IC data viewing and reporting

Track 3: Specifications

- Subtrack 3.1: National guidelines for IC QC/QA specifications
- Subtrack 3.2: Expert Task Group (ETG) for AASHTO IC specification development
- Subtrack 3.3: Technical support for States specifications development and customization

Track 4: Technology Transfer and Training

- Subtrack 4.1: IC workshops and certification
- Subtrack 4.2: IC field demonstration
- Subtrack 4.3: IC website and knowledge base

Figure 6.4: IC Implementation (How Can I Implement Intelligent Compaction? 2018)

7. The Connection Between the Technologies

In this study, these intelligent devices will coincide together in creating an optimal construction project. These technologies aim to increase productivity, safety, quality, and overall, the life-expectancy of the road. Each of these technologies are unique, but will benefit the State greatly. The State will receive better quality roads, be able to keep track of the project, and know the details of progress, what materials are needed, timeline of completion to communicate to the public, and the cost. E-ticketing will help contractors remain in contact with their workers to check on their headway. Figure 7.1 shows what an ideal e-ticket would look like once received electronically. This also allows contractors knowledge of load time to hold workers accountable (Iowa DOT 2016). Contractors will be able to determine why trucks are late (whether it be traffic situations, off-task breaks, etc.), and how many trucks they need on the project. By knowing this information ahead of time, contractors will be able to find discrepancy, hold accountability, and spend money more wisely. “Unlike traditional random sampling, continuous testing uses multiple inputs to ‘look for’ failure zones and has a high probability of detecting defects before they lead to premature failures” (Sommerfeldt 2018). Figure 7.2 shows continuous sampling can cover 100% of the mat. An example of the technologies utilized in practice developed in the “beginning (of) 2016, Alaska DOT used the IC and PAVE-IR paver-mounted thermal scanner technologies as contractor pay factors as part of project acceptance... They plan to offer bonuses for increasing the asphalt compaction averages – and require remediation for compaction below the standards” (Sommerfeldt 2018).

Emailed Ticket



TICKET #7010469 DATE Sep 14, 2016

PLANT 7 TRUCK 25 DRIVER MICHAEL ARMSTONG
 ORDER# 180 PO# JOB#
 CUSTOMER# 55 PROJECT# 55116 PROJECT NAME BLANKET - DES MOINES 2016

SOLD TO: NEHRING CONSTRUCTION, INC.
 DELIVER TO: 6210 NE 14TH DSM**COOPER

PRODUCT NO.	QTY	UNIT	DESCRIPTION	UNIT PRICE	AMOUNT
1533	7	cy	4000 COMM- INTERIOR		
HAUL	7	ly	READY MIX TRUCK HAUL CHARGE		
SUB TOTAL:					
TAX:					
TOTAL:					

ORDERED: 110.00 DELIVERED: 42.00 SLUMP: 6.00

SIGNED BY: Test
 TERMS AND CONDITIONS ACCEPTED

NOTES:
 Air 7 Slump 3 Temp 75 Test

Test

LOAD TIME: 11:27:03 MAX WATER ALLOWED: 0.00 WATER ADDED @ PLANT: 0.00 WATER ADDED @ JOBSITE: 10.00
 W/C RATIO @ PLANT: W/C RATIO @ JOBSITE:

	ACTUAL	MOISTURE	TARGET	UNIT
SAND	11180	3% (335.40)	11139	lb
COM-L/S	11880	1% (118.80)	11920	lb
CEMENT	3020		3024	lb
WATER	171		171	gf
FAC	840		756	lb
MRWR	189		189	oz
HOT	0		0	gf

Figure 7.1: E-Ticket (Iowa DOT 2016)

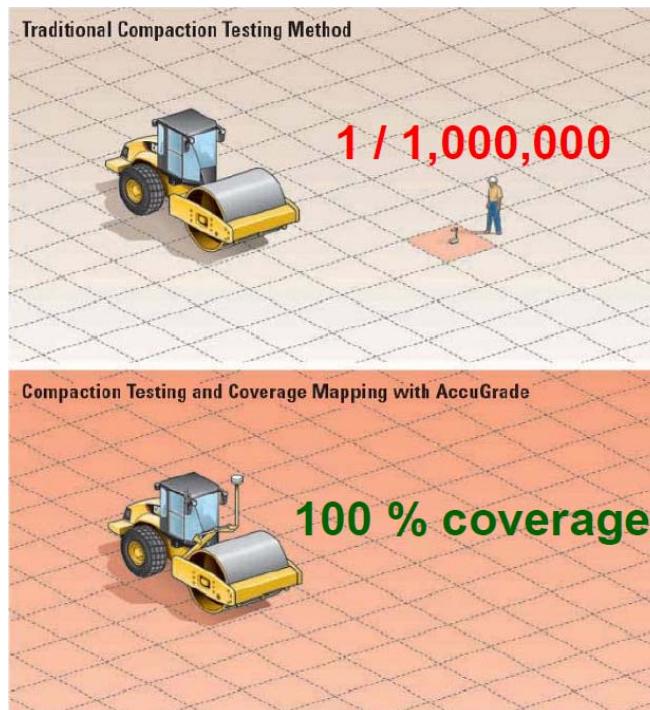


Figure 7.2: Intelligent Compaction Results (Willoughby 2014)

Another advantage of these technologies is to hopefully reduce the number of fines. For example, if the State tests the road during the trucks initially paving it, and they fail the density test, the contractor is fined. While using intelligent compaction and the paver mounted thermal profiler, personnel can adjust problems by using real-time screening from their sensors to re-correct the road. Therefore, a better quality road during the project equals less potential fines. The goals of these two technologies working together is early detection of mistakes and possible weakness in the development of the road. If the contractors invest the money initially, the technology will pay off in the long run. Contractors will have less future maintenance of the road and the State will no longer have to continuously rehire for preservation. In favor, contractors will have a better product and potentially gain jobs outside of state due to their quality project development. In Figure 7.3, the Kentucky Transportation Cabinet identifies the amount of infrastructure they must maintain and improve. The State has little resources to keep up with this growing statistic, hopefully with the help of technological advancements they will be able to reduce costs and enhance longevity.



Figure 7.3: KYTC Statement (Kentucky.gov 2018)

Continuing, these technologies should ideally all be accessible wirelessly. Eventually, the future outcome would be to get them all on the same application working simultaneously together. Of course they would need to get the licensing to work together. However, this would promise to be more convenient and less systems to look at. It would also be desirable to cut back on an inspector having to be at the job site every day because the abilities from the implemented technologies would cover a large percentage of the work an inspector has to do. Fundamentally, the devices will allow technicians to cover multiple jobs at once. They will help inspectors report immediately if there is a delay or issue in production.

Safety will be a large benefactor with these technologies. Inspectors will no longer have to walk up to the truck to get a loading ticket, where incoming traffic in their lane can be a concern or the truck itself, so they are safer using the e-ticketing process. Secondly, they will not have to measure the temperature of the mat because the infrared scanner will detect it for them and display and record it on a smart-device. It can be quite dangerous for inspectors to travel between paver equipment and roller machines, especially if the operator cannot see them. Thirdly, this can prevent inspectors from a fall or a trip onto the mat where they may get burned from the high temperatures of the asphalt. Figure 7.4 shows *in the intelligent compaction and infrared scanning field projects*, submitted by the Missouri Department of Transportation, with heat rising off of the mat from the intense temperature of the asphalt being laid and the dangers that it can lead to (The Transtec Group 2018). Due to intelligent compaction and paver mounted thermal profiler technology the inspectors do not need to get close to measure for cold spots or density issues, but rather read the data from a screen. In conclusion, these technologies can save a lot of time by preventing testing stops due to uncertainty and collect data continuously throughout the whole project to see the progress while keeping inspectors safe.



Figure 7.4: Missouri Intelligent Compaction (The Transtec Group)

8. Limitations

There are limitations to consider. There is a possibility of inconsistent data exchange, which would not relay the data correctly. A disconnection between information abstracted from the paver to the tablet or other smart device, data base information retrieval lost, or hardware connection problems (such as the GPS) losing service could throw off the collection of data. There will always be technical challenges that impede construction, but corrections can be made to prevent these issues, such as working with cell-phone providers to get towers stationed nearby or Microsoft programs to update software to possibly decrease lagging. Because of the advancement of this technology, companies will struggle to adapt due to their reluctance to change. A limitation on the technological device of intelligent compaction can be identified with:

“The growing interest among transportation agencies and contractors to incorporate IC technologies into earthwork and HMA pavement construction practice. Expectations are that the IC systems will: 1) improve construction efficiency; 2) streamline quality management programs of earthwork and asphalt projects; 3) provide a link between quality acceptance parameters and pavement design parameters; and 4) improve the performance of compacted materials. These expectations cannot be met without addressing the following key implementation challenges, such as: lack of adequate knowledge about technical aspects; no widely accepted specifications or standards; limited number of well-documented case histories demonstrating the benefits of IC; inadequate education/training materials” (White 2010).

9. Research Approach and Data Capture (Including Inspection Requirements)

Table 9.1 describes the inspection requirements that will be monitored within the test projects for this study.

Table 9.1: KYTC Inspection Requirements

Inspection Operation	Inspector Responsibility	Study Investigator Responsibility	Technology Employed
Ticket Receipt & Acceptance	Collect tickets and communicate with Study Investigator	Compare paper ticket information, delivery and dump times with Fleetwatcher data	Earthwave Technology (E-Ticketing: Integrated GPS, GIS, and plant weighing operations)
Tracking Theoretical Tonnage	Determine theoretical tonnage by station and communicate with Study Investigator	Compare theoretical tonnages as determined by Fleetwatcher and Inspection staff	Earthwave Technology (E-Ticketing: Integrated GPS, GIS, and plant weighing operations)
Visual Inspection for Segregation in the Truck	Inspect for Segregation	N/A	N/A
Temperature Monitoring in the Truck Bed & Paver Hopper	Take temperature readings as normal and communicate with Study Investigator	Track temperatures by station and location to compare to Pave IR data	Pave IR (Temperature sensors mounted on paver)
Temperature Monitoring Behind the Paver and Screed	Take temperature readings as normal and communicate with Study Investigator	Track temperatures by station and location to compare to Pave IR data	Pave IR (Temperature sensors mounted on paver)
Monitoring Paver Gates and Loss of Material	Review theoretical tonnage and check paver	Communicate with inspection staff and review Fleetwatch tonnage data. Does theoretical tonnage raise "red flags?"	N/A
Checking Pavement Depth	Check as Normal	N/A	N/A
Monitoring Roller Operation (as per test strip)	Check as Normal	Intelligent Compaction (IC) roller should illustrate rolling needed to operator	Intelligent Compaction
Visual Inspection of Pavement during Rolling	Check as Normal	N/A	N/A
Communicating with Contractor QC for Nuclear Density Measurements	Check as normal and communicate with Study investigator	Compare densities and locations to data should be available by IC roller	Intelligent Compaction
Marking Verification Core Locations & Core Possession (if needed)	Check as normal and communicate with Study investigator	Compare core density and location to intelligent compaction data	N/A

The following proposed tasks indicate how this study will be approached:

Task 1: Work with District 7 management to identify three to five test projects.

Task 2: Add the special notes for using e-Ticketing, PaveIR, and Intelligent Compaction to the bid packages of the selected test projects. Special notes for all technologies are attached in the Appendix B, C, and D.

Task 3: Work with the District 7 staff and contractors to plan and initiate the study plan, gain or plan access to the data, and communicate schedule and timelines.

Task 4: Communicate schedules of paving operations with the Study Investigators.

Task 5: Study Investigators will observe and collect data during the paving operations of the test projects as described in the table above.

Task 6: Tonnage, delivery, temperature, and compaction data will be compared and reported.

Task 7: A final evaluation the data and technology used will be reported.

10. Potential Outcomes

This study, implementing the three technologies, could potentially provide enough data analysis to show significant improvement and progress made in the project that would help reduce the workload on inspection staff, increase safety and communication, and amplify road quality. While also, hopefully allowing a reduction in spending. With the State having less and less resources to contribute to jobs, implementing these technologies is a unique and beneficial alternative to the problem. Furthermore, with the ability to run jobs without a technician on site at all times the State will be save in cost and heighten safety satisfaction. Communication between contractors, industry, personnel, and the project site will increase when keeping better track of the trucks at the job, getting rid of paperwork, and having on-hand, real-time progress of the job.

11. Conclusion

As technology develops throughout the world, transportation is constantly having to keep up with the demands of growth and efficiency while maintaining a cost-effective project that is safe and allows for a quality life-expectancy. The three technologies discussed in this thesis have been proven to be beneficial through research and application. E-Ticketing can eliminate paper, enable real-time document use, create viewing availability for all project partners, and maintain a safer work environment. The Paver Mounted Thermal Profiler allows contractors to fix defective sections immediately, evaluate materials by measurement of their surface temperature and its variations, and benefit the life of the road by detecting cold spots, increasing the life of the road and saving on maintenance costs. Lastly, Intelligent Compaction is one of the most important processes in transportation construction, which strengthens and stabilizes uniformity of pavement materials, and in turn, achieves a durable roadway. Implementing this technology would significantly impact roadway construction, efficiency, cost, safety, and time management. The Kentucky Department of Transportation would benefit from these technological advances in the long run due to producing stronger, quality roads and developing a faster system that saves in resources while communicating data systematically with all partners involved.

Appendices

Appendix A: MOBA Paver Mounted Thermal Profiler Estimate



MOBA Corporation
 1000 MOBA Dr.
 Peachtree City, GA 30269
 Phone: 678-817-9646

ESTIMATE

DATE
10/5/2017

Estimate Number
18135

NAME / ADDRESS
Moba Corporation 180 Walter Way Ste 102 Fayetteville GA 30214

Ship To
Cyde Newcomer University of Kentucky

P.O. NO.	TERMS	Contact
	Net 30	GM

ITEM	DESCRIPTION	Lot Number	QTY	PRICE	TOTAL
	This estimate will equip a paver with (1) MOBA PAVE-IR MTPS-100 system (scanner) with a wheel odometer. Depending on the type of catwalk/stairs on the machine the telescoping mount base may need to be welded on by the contractor for the MOBA technician. Freight is not included in this estimate. Please allow 3-4 weeks from point of purchase for delivery/installation and training. Training to be provided after the installation is complete on the same trip. Please contact Gary Motak @770-842-1579 after you have purchased your system to arrange installation. The (ASPA) Application Software Provider Agreement for the eRoutes (cloud) subscription can be obtained from Shawn Ensell or Gabby Lawson at 678-817-9646. **THE ASPA AGREEMENT MUST BE COMPLETED AND RETURNED BEFORE THE SYSTEM CAN SHIP**.				
Pave IR MTPS100 ...					
04-02-15275	Cable for MOBA memory drive with USB-A plug for PC - work with MOBA Operand	K.4.A.	1	252.00	252.00
04-02-50123	8m Straight, 7 pol Power/CAN 1 Cable, Operand D, open end	H.6.D	1	233.10	233.10
04-02-50091	5m, Straight Cable, 5pin M12 to 4pin Clic-Lock, Pave-IR	K.4.C.	1	315.00	315.00
04-02-50155	5m, Straight Cable, 5soc M12 to 7 soc Bayonet, Pave-IR SCANNER ONLY	H5E	1	252.00	252.00
04-02-50087	2m, Straight Cable, Extension 4 soc to 4 pin Deutsch	K.4.B.	2	94.50	189.00
04-02-50088	3m, Straight Cable, Extension 4 soc to 4 pin Deutsch	K.4.B.	1	119.70	119.70
TOTAL					



MOBA Corporation
 1000 MOBA Dr.
 Peachtree City, GA 30269
 Phone: 678-817-9646

ESTIMATE

DATE
10/5/2017

Estimate Number
18135

NAME / ADDRESS
Moba Corporation 180 Walter Way Ste 102 Fayetteville GA 30214

Ship To
Cyde Newcomer University of Kentucky

P.O. NO.	TERMS	Contact
	Net 30	GM

ITEM	DESCRIPTION	Lot Number	QTY	PRICE	TOTAL
04-02-50089	4m, Straight Cable, Extension 4 soc to 4 pin Deutsch	K.4.C.	1	144.90	144.90
04-02-50126	5m, GPS Power Cable, Novatel SMART Antenna	H6D	1	571.32	571.32
04-01-04035	AC Adaptor for Operand D		1	219.08	219.08
04-02-50086	1.8m A/C Power Adaptor, US Version (6ft)	K.4.B.	1	8.43	8.43
	Pave IR MTPS100 Cables Wheel Odometer				2,304.53
Pave IR MTPS100 ...					
04-80-12300	MTPS-100 MOBA-Thermal-Profil-Sensor100, Scanner		1	10,432.50	10,432.50
04-06-50078	Pave-IR Carry Case, Black, Scanner	A.4.C	1	395.90	395.90
03-05-00310	Distance Encoder, CAN, PAVE-IR	K.5.E.	1	1,668.39	1,668.39
01-17-01885	3" Magnet mount for Encoder	K.4.E.	1	195.30	195.30
05-55-50001	Moba-Operand, type D, COM2, PAVE-IR, 3G GPRS	MFG area	1	9,576.50	9,576.50
04-05-50842	1.5" Ball Ram Mount, Large Rectangular Base Plate	K.5.E.	1	189.00	189.00
05-07-50000	SMART Ag GPS, MCA Config, with Mounting Plate	K.6.D.	1	3,536.35	3,536.35
03-05-02040	Moba Drive for Operand, Blue		1	280.87	280.87
06-03-00056	Pave Project Manager Software		1	95.49	95.49
06-03-50001	1 YR Subscription/Renewal for eRoutes Data Service, Pave-IR		1	1,500.00	1,500.00
04-05-50868	6ft Telescoping Mast, Square tubing	L.4.B.	1	480.00	480.00
04-05-50869	Scanner Mount for mast, with GPS Mount	L.4.D.,L.4.E	1	660.00	660.00
01-17-50392	6" Encoder Extension Tube, PAVE IR Rev: 1.00	E.12.A	1	66.00	66.00
Kit Discount	Kit Discount		1	-380.83	-380.83
	Pave IR MTPS100 Brackets/Electronics Wheel Odometer				28,695.47
09-01-00400	Installation & Training		1	3,000.00	3,000.00
				TOTAL	\$34,000.00

Appendix B: E-Ticketing Special Note

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.

<u>Code</u>	<u>Pay Item</u>	<u>Pay Unit</u>
	HMA ELECTRONIC DELIVERY MANAGEMENT SYSTEM	EACH

Appendix C: Paver Mounted Thermal Profiler Special Note

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 $\pm 2.0\%$ 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
- Surface temperature of each of the sensors

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 $\pm 2.0\%$ 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° \square 25° F, Moderate 25.1° \square 50° F and Severe $>50^{\circ}$. 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.

<u>Code</u>	<u>Pay Item</u>	<u>Pay Unit</u>
24891EC	PAVE MOUNT INFRARED TEMP EQUIPMENT	SQFT

Appendix D: Intelligent Compaction Special Note

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 Section(s)
Requirements

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.

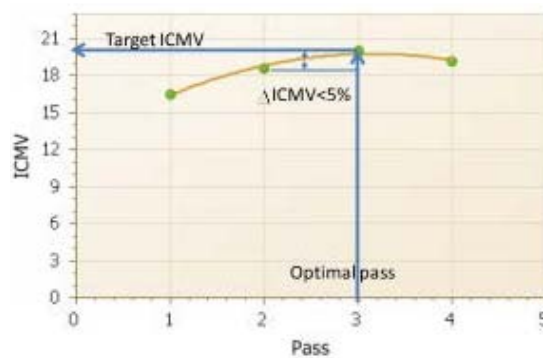
B. Construction Test Section(s)
Requirements

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 area evaluation. IC Construction areas may extend over multiple days depending on the operations.

The IC Construction Operations Criteria does not affect 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.

<u>Code</u>	<u>Pay Item</u>	<u>Pay Unit</u>	
24781EC	Intelligent Compaction for Asphalt	TON	May 4 th , 2015

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 - c) Graduated Summa Cum Laude
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