71 Towards an Automated Asphalt Paving Construction Inspection Operation

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Abstract

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. Challenges to the system include connectivity, interoperability, and usability. The contribution of this paper is to provide a framework in which to combine these commercially available technologies into a multi-faceted, enhanced inspection approach.

Keywords

Asphalt paving • Remote inspection technology • E-ticketing • Intelligent compaction

71.1 Introduction

Evolutions in the business models that State Transportation Agencies (STA) use for the development of highway construction projects are driving changes in their construction staffing needs. These changes are driven by several factors including: (1) fluctuations in funding levels (e.g. lean periods of state funding followed by the influx of federal stimulus funding); (2) dynamic sources of funding (i.e. changes in how projects are funded) across STA project portfolios (e.g. local vs. state vs. national, public-private partnerships, or any combination of funding agencies); (3) alternative contracting methods (e.g. design-build, QA/QC practices, warranty contracts); (4) changes in traditional job responsibilities (e.g. integration of construction and maintenance departments); (5) increased use of consultant services to augment in-house personnel (e.g. design outsourcing, construction inspection outsourcing); (6) changes in project requirements (e.g. increased environmental mitigation requirements for planning and construction); and (7) advances in design and construction technology (e.g. GPS machine control, 3D design). These evolutions occur at a time when STAs are experiencing significant staff turnover. Experienced personnel are leaving STAs through retirement and being replaced by less experienced personnel

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I. Mutis and T. Hartmann (eds.), *Advances in Informatics and Computing in Civil and Construction Engineering*,
https://doi.org/10.1007/978-3-030-00220-6_71

who are encountering more rapid increases in responsibility earlier in their careers than their predecessors. In some STAs, retiring personnel are not being replaced at all. These changes are impacting all divisions of STA personnel, particularly those tasked with the construction of highway infrastructure.

71.2 Background

These personnel transitions are also occurring at a time when STA human resources are decreasing as the volume of lane-miles managed is increasing. NCHRP Synthesis 450 [1] found that among 40 STAs between 2000 and 2010, state managed lane miles increased by an average of 4.10%, while the number of full-time equivalent staff decreased by 9.7%. When full-time equivalents were normalized across the managed road system, the responding STAs full-time equivalents per million dollar of disbursement on capital outlay decreased by an average of 37.3%. Compounding these challenges are recent demographics of STA construction staff, which indicated that the most frequent age range of construction staff was 40–50 years old and that the average years of experience was 10–15 years [1]. This indicates that STA construction staff will continue to experience a loss in knowledge and skill due to retirements. This is leading STAs to utilize Construction and Engineering Inspection (CEI) consultants to assist in project delivery. NCHRP Synthesis 450 reported that 96% of STA respondents indicated that their agencies were using CEI consultants to assist in executing construction projects [1].

Although there is an increased use of CEIs across STAs, their reception has been mixed. Given those challenges and the limited STA inspection staff, there is an opportunity to leverage technology. Construction inspectors conduct a variety of QC/QA services, but one of the most significant efforts in Kentucky is asphalt paving inspections. Asphalt paving inspections are also ideally suited for technology deployment due to the quantitative nature of many of their responsibilities. The primary objective of this research effort is to propose a theoretical framework for the automation of asphalt paving inspection operations by leveraging existing technologies. The findings will be used in future work to test the effectiveness of the proposed framework compared to traditional practices on actual asphalt paving projects. Table 71.1 outlines a list of typical inspection duties and potential technologies to assist in those operations.

71.3 Framework

71.3.1 Potential Technologies

After mapping the responsibilities for inspectors on asphalt paving projects, technologies were identified in the third column of Table 71.1. Three identified technologies allow for the automation of many of the quantifiable, typical asphalt inspection tasks. Those technologies are electronic ticketing (e-ticketing), paver mount thermal profiling, and intelligent compaction and are discussed in detail in the following sections.

71.3.2 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. A combination of GPS units in critical equipment (haul trucks, batch plant, and paver) with a GIS

Table 71.1 Asphalt Paving inspector duties and potential technologies

Inspection operation	Inspector responsibility	Technology employed
Ticket receipt and acceptance	Collect tickets	E-ticketing: Integrated GPS, GIS, and plant weighing operations
Tracking theoretical tonnage	Determine theoretical tonnage by station	E-ticketing: Integrated GPS, GIS, and plant weighing operations
Temperature monitoring in the Truck Bed and Paver Hopper	Take temperature readings as normal	Paver mounted temperature profiler
Temperature monitoring behind the Paver and Screed	Take temperature readings as normal	Paver mounted temperature profiler
Monitoring roller operation (as per test strip)	Check as normal	Intelligent compaction
Communicating with contractor QC for nuclear density measurements	Check as normal	Intelligent compaction

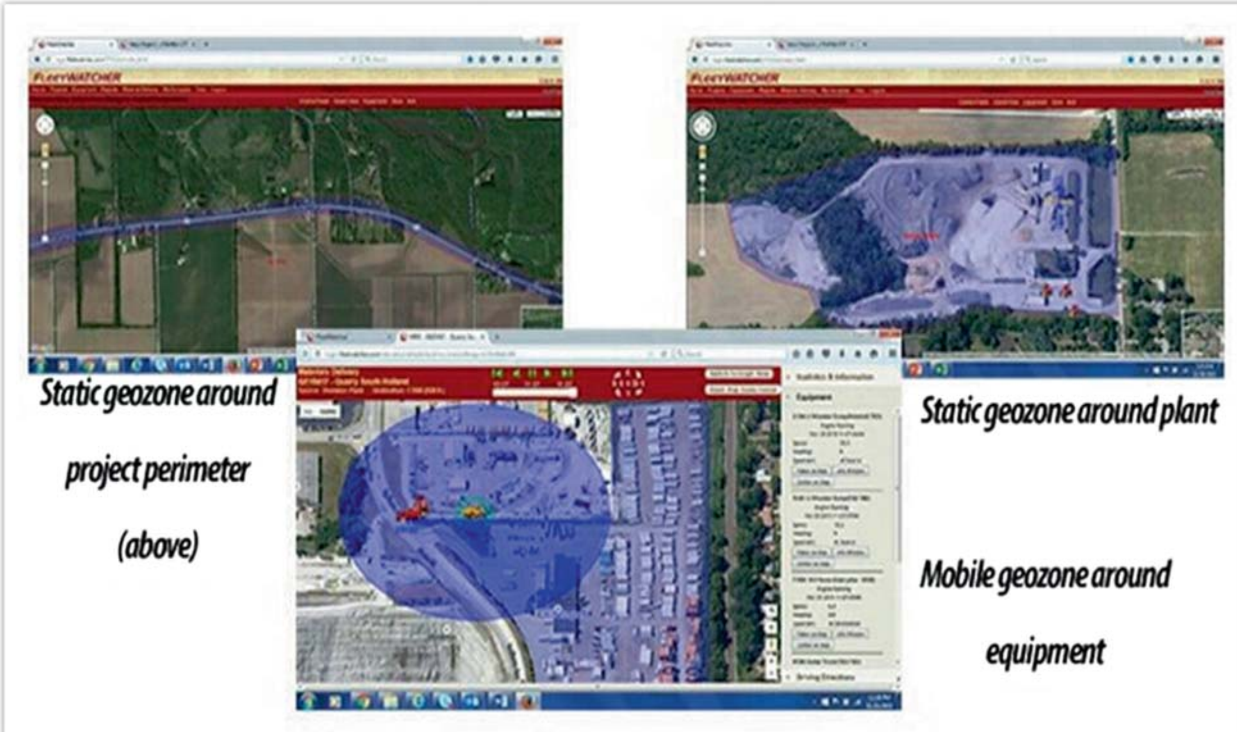

Fig. 71.1 E-ticketing Geozones [2]

interface allows inspectors to track load information and hauling information for project monitoring and documentation. The technology requires the establishment of geozones 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) (see Fig. 71.1) [2]. 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. While this effort proposes its use on asphalt paving, the technology is flexible to meet other similar material delivery and storage operations. Additionally, the software also works 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 [3]. Additionally, a geozone around the entire project detects when the truck enters and leaves the project zone, but also a smaller geozone around the actual paver allows inspectors to know when the truck is engaged with the paver. This is very important because trucks waiting on other trucks to finish dumping is inefficient and can potentially negatively impact quality. Since it is vital to not have back log or wait time, 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. With this technology, the inspector will be able to multitask using mobile devices. After accessing the electronic delivery ticket for the material, the e-ticket can be linked to the daily work report for measurement and payment [4].

71.3.3 Paver Mounted Thermal Profiler

Temperature of the asphalt mix at placement is a key quality indicator for the long-term performance of the pavement. Colder placement temperature makes for less effective compaction efforts and thus a lower density final pavement. Thus, many STAs require spot checks for surface temperatures of the paved surface, however, this does not provide for a full representation of the temperature across the mat. Recent developments have allowed for this data capture through a paver mounted thermal profiler. This technology is an infrared scanner that is placed on the back of a paver. Once installed, 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

Fig. 71.2 Paver-mounted thermal imaging profile [6]

spots or streaks in the mat which directly relate to lower density sections [5]. 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 placed on the paver that can show real-time results of the scans, each scan records thermal data of the mat (see Fig. 71.2) [5]. One such system is called PAVE-IR which allows for process optimization and documentation in road construction [6].

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. 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" [6]. This combination of the innovative tool accurately depicts measurement to evaluation.

There have been several other STAs to successfully utilize infrared temperature monitoring on a pilot project including Iowa and Texas. The PAVE-IR system by MOBA is one such system that costs roughly $34,000 for each pavement operation or $18,000 to rent the equipment for a two-month project. The price for a rental of the equipment covers a $3000 installation charge, plus an additional $7500 charge per month of rental. Devices such as a Microsoft tablet will allow an inspector to see the pavement data given. Java, Adobe, and MOBA Pave Project are pre-installed on the device. This will allow for data transmission close to real time. 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 [6].

71.3.4 Intelligent Compaction

Intelligent Compaction is a process that involves the usage of modern vibratory rollers equipped with an in situ measuring system that allows for constant feedback to the roller operator [7]. Additionally, GPS technology is used for project mapping, combined with software that automates the documentation from the project rollers [7]. Compaction rollers equipped with Intelligent Compaction technology also maintain a continuous record of color-coded plots that include the number of roller passes, computer generated material stiffness measurements, and the location of the roller on the project limits [7]. The GPS system is vital for accurately locating the roller along the project area [8]. The system may be a combination of using a single or multiple real-time kinetic system with an on-site base station or virtual reference station, depending on the terrain of the project site [8]. With the antenna placed on the top of the roller cab, the effective range of a GPS station on a project may be approximately 2 miles long when the line of sight is unobstructed [8]. By monitoring the position of the roller along the project area, the measurements that are recorded correspond to a certain location. By providing the relation between the location on the project and the measurement recorded, a picture can be created of the overall compaction consistency on the project [9].

An accelerometer is a key component of the Intelligent Compaction system that is mounted near the vibratory drum of the roller [8]. Double drum rollers, as are commonly used for asphalt compaction, may have two accelerometers, with one mounted near each drum [8]. The function of the accelerometer is to measure the vertical acceleration of the roller frame as it progresses along the project area [8]. The vertical acceleration that is recorded by the accelerometer is then used to indicate stiffness values of the material.

Temperature sensors may also be used on an Intelligent Compaction roller system to monitor the temperature of the surface of the asphalt material. Mixes are best compacted within certain ranges to avoid any "tender zones" that may occur on a project area [8]. These areas normally occur within the range of 219–230 °K, and permanent damage may be caused to the asphalt material if it is not correctly monitored while compaction operations occur with materials within this temperature range [9]. By monitoring the surface temperature of the mixture constantly, the roller operator can see temperature variations in real time, showing the operator when to begin rolling and when to stop [9]. A surface temperature record can also be created for the project and allow for better records to be kept throughout the project and enhance project administration [8].

Visual display is key for the Intelligent Compaction system to display real time compaction information, in both numerical and graphical form so that appropriate adjustments can be made [8]. Displayed information can range from parameters such as roller amplitude, frequency, GPS location, and speed [8]. The effects of the roller are displayed in various colors so that the operator can visually track the progress over along the project, monitor the increase in layer stiffness, and ensure a more uniform compaction coverage [8].

Finally, data can be stored and processed from the Intelligent Compaction roller. Each proprietary software can convert the vertical acceleration from the accelerometer to downward displacement and combine with the other collected information to create a continuous profile of the level of compaction along the project [8]. Data from the roller can be stored and downloaded at any time for further analysis and documentation [8].

Some systems may be equipped with automatic feedback controls (AFC), which can regulate system components such as roller vibration, amplitude, and frequency [7]. The AFC system can allow the roller operator to receive quick feedback regarding how the project environment and materials are responding to compaction efforts [7]. This quick feedback can lead to more correct decisions being made, and ultimately a greater ability to increase project quality control in real time [7].

While Intelligent Compaction does not differ in the way in which asphalt compaction occurs, as it is still dependent upon the combination of the weight of the roller machine and the vibratory system, it does offer benefits to producing a better final product. Intelligent Compaction allows the roller operator to answer questions such as where the last roller pass stopped at, whether the return pass covered the proper area, and did the previous pass have the proper overlap [9]. The Intelligent Compaction system also allows for the roller operator to monitor the asphalt mat temperature to ascertain when the best time to begin rolling is, without confirmation from some other project personnel who may not be constantly available to answer questions [9]. For projects that also require night paving work in order to be completed on schedule, Intelligent Compaction has multiple benefits in projecting the progression of compaction work for the roller operator to identify and evaluate in real time, which would be much more difficult under the poor lighting conditions normally found during night operations [9]. By incorporating measurement capabilities within the compaction roller, it is possible to ensure that project specifications and requirements are being met in real time. By meeting specifications during the initial compaction process, overall quality can improve, along with maximized productivity, reduced rework, and minimized costs [10].

71.4 Results of Previous Studies

71.4.1 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 varies 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 [4].

As of 2017, there are many offices that have implemented e-ticketing technology into their resources. 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 [4]. Michigan has recorded massive savings along with the effective use of their inspector's time.

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" [3]. Iowa plans to work with their industry partners closely to communicate when their material ships, processes, and enters the project.

71.4.2 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 poor sections immediately, rather than after failure. This method could also increase safety of the paving operation by reducing 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, materials can be evaluated 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 [5]. Increasing the life of the road directly correlates with the decrease in maintenance costs. IR analysis can come in multiple forms; including paver stops, passes, and temperature profile readings [5].

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 ft 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 s" [5]. 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 [5]. 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" [5]. However, it must be considered for quality thermal readings that the proper equipment is used and purchased. Trucks with good beds, material transfer vehicles (MTV) with remixing capability, paved automation, and so forth will make the Paver Mounted Thermal Profiler perform adequately.

71.4.3 Technology 3—Intelligent Compaction

The major benefits of IC can be categorized as improved density, increased productivity, reduction of repair costs, continuous record, identification of non-compactable areas, and improved depth of compaction. 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" [7]. To further understand overcompaction, it is defined by the "crushing of aggregate or low air void content, leading to rutting or flushing" [11].

71.5 Model Framework

In this study, these intelligent technologies, when merged together, provide an opportunity to collect rich, accurate quality inspection data. 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 Kentucky Transportation Cabinet (KYTC) greatly. KYTC 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. This also allows contractors knowledge of load time to hold workers accountable [3]. 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" [11]. 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" [11].

Another advantage of these technologies is to reduce the number of penalties due to poor performance. For example, if KYTC 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 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. KYTC has few 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.

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. 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.

A proposed asphalt inspector dashboard displayed in real-time on a mobile computing device will allow for remote inspection of asphalt paving projects. Thus providing KYTC will the ability to provide high quality inspection activities with the limited human resources available. Each technology collects GPS data that can be tied to project station points, thus, batches from the electronic ticket can be tied to thermal profiles and later compaction values. Thus if quality issues arise later, KYTC can quickly see if it could perhaps be traced back to tracking/delivery, paving, or compacting. With that information, the appropriate maintenance activities can be determined.

71.6 Limitations

There are several limitations anticipated. 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, database information retrieval lost, or hardware connection problems (such as the GPS) losing service could throw off the collection of data. There will likely be issues at the human-technology interface. With training and repetition, contractors and KYTC personnel should make improvements in acquiring the data and making informed decisions with it. In addition, these technologies are commercially available, and thus, creating an inspector's dashboard by merging data from multiple platforms may cause proprietary issues.

71.7 Future Work

An urban, re-surfacing project in the state of Kentucky will be deploying the proposed technologies during the 2018 paving season. The researchers will be concurrently evaluating performance, documenting best practices, and finally, making recommendations and comparisons to traditional asphalt inspection practices on this project. Depending on future project lettings, the research will also be conducted on smaller, rural projects and a larger highway re-surfacing project in 2018.

71.8 Conclusions

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, safe, and lasting project. The three technologies discussed have been proven to be beneficial through prior 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 and saving on maintenance costs. Lastly, Intelligent Compaction strengthens and stabilizes uniformity of pavement materials, and in turn, achieves a durable roadway. Implementing these technologies concurrently would significantly impact roadway construction, efficiency, cost, safety, and time management. The Kentucky Transportation Cabinet would benefit from these technological advances in the long run by producing stronger, quality roads and developing a faster system that saves in resources while communicating data systematically with all stakeholders. As resources for STAs are reduced, leveraging technologies such as those proposed has the opportunity to maintain a high level of quality and service while managing with fewer personnel.

Acknowledgements/Disclaimer The authors wish to thank the Kentucky Transportation Cabinet (KYTC) for their support of this work through KYSPR 18-554. Commercial entities, equipment, or materials may be identified in this document to describe an experimental procedure or concept adequately. Such identification is not intended to imply recommendation or endorsement by the authors or KYTC, nor is it intended to imply that the entities, materials, or equipment are necessarily the best available for the purpose.

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