# IMPROVING QUALITY CONTROL OF HOT MIX ASPHALT PAVING USING INTELLIGENT COMPACTION TECHNOLOGY

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ABSTRACT

This paper answers the question: Can existing Intelligent Compaction (IC) technology be used in a practical way to improve the quality control (QC) process for Hot Mix Asphalt (HMA) paving projects? Specifically, the paper investigates the use and benefits of IC technology for tandem drum vibratory rollers used to construct HMA materials.

There is a need to improve QC practices for most typical HMA paving operations based on the observations by the authors. The paper identifies and discusses major shortcomings in both conventional compaction equipment and current QC practices. The use of IC technology can address these shortcomings and provide innovative QC tools to contractors and agencies.

The paper is based on the findings of the Intelligent Compaction Pooled Fund (ICPF) project that included 16 field demonstration projects in 12 participating states. The ICPF projects were actual highway construction projects where various pavement materials were placed and compacted using both conventional compaction equipment and rollers that were equipped with IC technology from various suppliers. Eight of the projects included placement and compaction of HMA materials. On these projects, IC was used for only a portion of the project. A case study of the Wisconsin project is used to illustrate the benefits that could have been obtained if IC technology and specifications would have been used for the entire project from beginning to end.
IMPROVING QUALITY CONTROL OF HOT MIX ASPHALT PAVING USING INTELLIGENT COMPACTION TECHNOLOGY

INTRODUCTION

Quality control (QC) during paving/compaction of HMA materials is defined as the producer/contractor’s responsibilities for testing, inspection and oversight of all of the materials and processes involved to ensure that a quality product that meets the specifications is obtained. QC is also called process control. The official FHWA definition of QC is actions and considerations necessary to assess and adjust production and construction processes so as to control the level of quality being produced in the end product (1). This paper will focus on the use of IC to improve QC procedures. It will not address Quality Assurance (QA). Figure 1 shows a flow chart of potential QC activities using IC technology during paving operations on typical asphalt pavement projects of various types, including new construction projects as well as HMA overlay projects on both existing HMA and PCC pavements.

Intelligent Compaction (IC) is a maturing technology in the United States that provides beneficial QC tools during construction of Hot Mix Asphalt (HMA) pavements (2). These tools offer unprecedented information and capabilities that could revolutionize the compaction industry. IC is defined as tandem drum rollers that are equipped with technology, hardware and software that work together to provide new and valuable tools to the contractor and owner/agency. The components of IC technology include Global Positioning System (GPS) technology, accelerometer-based measurement systems and temperature readings.

Compaction is the important final step in the construction of long-lasting asphalt pavements. It is well understood that a poorly compacted HMA pavement is unlikely to obtain its expected service life. Shorter-than-expected pavement life will result in extra maintenance and resurfacing costs. Conventional compaction equipment processes and QC procedures have shortcomings, which often result in poor density results. Therefore, any improvement to either the compaction process itself or to the QC or acceptance procedures being employed will lengthen pavement service life and result in real cost savings.

It is important to first have an understanding of the shortcomings of both the conventional compaction equipment and QC practices currently being used in order to comprehend the role that IC can take in improving QC of HMA paving projects. First, there are shortcomings in the conventional compaction process itself. Conventional compaction equipment does not allow for any, or very little, “on the fly” feedback to project personnel. Typically, using a standard vibratory roller, a fixed number of passes are applied to the material being compacted. The problem with this is that there are a number of critical factors that can vary during construction operations. These factors include support from underlying materials, lift thickness, materials type and asphalt mat temperature. The changes in these critical factors are invisible to the roller operator during conventional compaction operations. The result is that either too little or too much compaction effort may be applied to the pavement material. IC would provide a better method because constant information is continuously reported to the roller operator related to pass count, the in-place pavement material density levels or other density-related properties.

The second major shortcoming of conventional compaction equipment is that overcompaction can easily occur and actually reduce the density that has already been obtained with previous passes. Overcompaction occurs when pavement materials that are already adequately compacted have one or more additional passes of a vibratory roller. When this occurs, displacement of the material does not occur and the vibratory roller can enter into the undesirable “double jump” mode where the roller is perceptively or imperceptibly bouncing on the pavement surface. This roller mode can be destructive to the pavement and actually cause a reduction in material density (and shear failure/dilation in soil materials). It is also possible to under-compact pavement material. This occurs when insufficient compactive effort is applied. IC would provide a better method to help the roller operator avoid over compaction (and under-compaction) by providing continuous feedback that allows the operator to obtain the optimum number of roller passes.
There are also shortcomings to the conventional methods of density QC. Typically, a small number of spot tests (with either cores or nuclear gauges) are run and a judgment about the density level of the entire roadway is made based on the results of this spot testing. Unfortunately, density measurement from a small number of spots may not be representative of the density of the entire lot. IC provides a better method because a color-coded map showing ICMV, mat surface temperature and pass counts of the entire roadway surface can be produced. In other words, IC provides 100% coverage of each of the project sections, making it possible to identify problem areas of low ICMV or improperly compacted material. This will allow contractors or agencies to identify areas of concern for further QC/QA testing, if desired. Another shortcoming of conventional QC activities is that density, or any density-related materials properties, are not measured until after the compaction process is complete. So, what if you find out that specification density was not achieved after rolling is completed? It is often too late to do anything about it. IC offers a better method because it may be possible to identify areas of low ICMV values (that may relate to low density) during the actual compaction process. With that capability, the roller operator and/or project personnel can identify areas that need further compaction (or maybe less compaction) during the process and apply the right compactive effort when conditions for effective compaction are optimum. IC is able to address both of the shortcomings in current QC methods mentioned above by providing the roller operator and QC personnel with access to unprecedented insight into the compaction process.

This paper is based on the findings of the recently completed Intelligent Compaction Pooled Fund (ICPF). FHWA/Transportation Pooled Fund (TPF) No. 954 “Accelerated Implementation of Intelligent Compaction Technology for Embankment Subgrade Soils, Aggregate Base, and Asphalt Pavement Materials” was completed in July 2011 (3). This paper will refer to this research project as the ICPF. ICPF was a three year project to study existing IC technology for a wide variety of pavement materials that require compaction using field projects in the twelve participating states. The ICPF was performed to support the FHWA Intelligent Compaction Strategic Plan (4). There were eight ICPF projects over the three year study that included HMA, including ICPF projects in Minnesota, Wisconsin, New York, Indiana, Mississippi, Maryland, Georgia and Virginia. This paper will reference some of the findings in these projects. The data obtained and findings of the ICPF project in Wisconsin will be used as a “case study” to illustrate how IC could have been used as a valuable QC tool to improve the service life of the HMA pavements placed on that project. The final project report for the Wisconsin ICPF project can be found on the IC website (5).

The overall findings of the ICPF demonstrated the benefits of using IC on HMA field projects. The immediate benefits include:

- Real-time feedback to the roller operator
- Permanent records of compaction data
- Statistical and geospatial analysis of IC data
- Mapping of underlying materials prior to paving/compaction

This paper will explain how IC technology can be used as a QC tool to improve the compaction process on HMA paving projects. A discussion of availability of IC technology from all of the various equipment suppliers will also be included.

BACKGROUND

While being implemented in Europe and Japan for years, the IC technologies have been introduced to the US fairly recently. Although equipment suppliers are making progress in developing IC technology and making it available in the United States (6), availability of IC equipped tandem drum vibratory asphalt rollers that fully meets the FHWA criteria is limited to a three suppliers. The addition of IC technology does increase the cost of the roller. Recent estimates show that the cost is approximately 30% higher compared to a standard vibratory roller.

There are a number of United States equipment suppliers that are beginning to incorporate at least some of the above-mentioned intelligent compaction capabilities into their tandem drum vibratory rollers.
However, FHWA has established a definition of IC that requires certain capabilities to be considered a “full” IC roller (7). FHWA definition for Intelligent Compaction (IC) rollers are vibratory rollers that are equipped with:

- Real-Time Kinematics (RTK) Global Positioning System (GPS) radio and receivers to provide horizontal and longitudinal tracking (e.g., roller positioning);
- Integrated measurement computer system to collect and analyze roller and pavement responses information;
- Accelerometers mounted in or about the drum to monitor applied compaction effort and resulting responses from the underlying layers;
- Temperature instrumentation to monitor the surface temperature of HMA material; and
- GPS-based documentation system that is capable of providing continuous roller generated data in real time during the compaction process on a color-coded on-board display. GPS equipment provided includes; a RTK-GPS (Real Time Kinematic-GPS) base station that records values in northing, easting, and elevation data in meters using the Universal Transverse Mercator (UTM) coordinate system.

At this time, each supplier of IC technology has developed or adopted a unique measurement methodology and terminology. Since the IC FHWA/Transportation Pooled Fund (ICPF) was intended to evaluate existing IC technology, there was no effort to standardize the measurement values. Therefore, there are five different measurement values from various suppliers evaluated during the research (8). A generic term that describes all of these measurement values in Intelligent Compaction Measurement Value (ICMV).

There are four United States suppliers of IC technology for asphalt compactors that are currently available, including Sakai America (9), Bomag Americas (10), Caterpillar and Hamm/Wirtgen. Caterpillar does not meet the FHWA criteria for IC technology since there is no measurement system included for their double drum IC rollers. Table 1 summaries the current features and capabilities of the IC technology for these four suppliers.

IC can be valuable for QC during HMA compaction operations in a number of ways. Most importantly, it can help identify and address problems that can have an adverse affect on pavement performance. In addition, it can provide a new tool to improve the compaction process. Specifically, IC can improve QC by:

1. Improving density, especially decreasing variability of density. By using the on-board, color-coded display can be used by the roller operator to clearly view roller passes in real time. This has been demonstrated to result in more consistent number of passes (at optimum pass count), which should result in less variability of achieved density.
2. Identifying soft spots in underlying materials prior to paving. By using color-coded mapping capabilities, repairs can be made to problem areas that could cause future maintenance problems.
3. Achieving 100% coverage of pavement layer being placed. Current QC practices rely on taking spot tests on limited locations on the compacted roadway. Using the capability to produce a color-coded map of roller passes, surface temperature and ICMV of the entire area being paved, areas that have potential issues can be identified and tested.

**INTELLIGENT COMPACTION AS A QUALITY CONTROL TOOL**

As part of the ICPF, researchers conducted field projects using IC rollers from various manufacturers. On each project, the following activities were performed:

1. Mapping of underlying layers
2. Improving the compaction process
3. Conducting statistical and geospatial analysis of IC data
Mapping of Underlying Layers

Results from IC compaction are best interpreted with knowledge of the underlying layer support conditions, which is a factor that has been difficult to quantify in the past. IC gives us a new tool that is the equivalent of advanced proof rolling as will be illustrated in this discussion. The research clearly showed that hard and soft underlying conditions tend to “reflect” through the upper layers affecting surface compaction. This aspect has not been addressed very well in IC specifications and in interpreting IC measurements to date (11). The research found that the same tandem drum vibratory roller equipped with IC technology that was used for HMA compaction can be used effectively for mapping of existing in-place layers.

The term “mapping” of the underlying materials refers to the process of using the tandem drum vibratory IC roller to measure the underlying material. The IC roller is driven over the underlying materials in the vibratory mode and ICMV is continuously recorded during repeated, side-by-side passes until the entire area has been covered. Mapping is generally performed at lower levels of amplitude and reduced frequency to avoid the vibratory roller going into the double jump mode and to avoid damage to the materials being mapped. Usually, some experimentation with various amplitudes and frequencies is tested initially to find the best combination. For example, the data is collected and processed to produce a permanent color coded map of the roadway that was mapped on the Minnesota ICPF project as shown in Figure 2. A related finding of the ICPF project is that the support characteristics of the underlying materials has a dramatic affect on the ability to compact the HMA layer on top of it. Where “soft” areas exist in the underlying layer, this tends to “reflect” up through the HMA layer being compacted on top of it. Conversely, the same is true of the “stiffer” areas of the underlying materials. It was found that it was easier to compact the HMA over those areas of better support. Figure 2 also shows a side-by-side comparison of the color coded mapping of ICMV measured during mapping of the subbase layer and during the compaction of the first layer of HMA. Because high precision GPS is used on the IC rollers, these maps can be compared accurately. Also, note the regression analysis in Figure 2 of subbase ICMV versus HMA ICMV that shows a good correlation between these two measurements.

Improving the Compaction Process

On each ICPF project, the research team conducted a process to determine if the compaction process could be improved. Specifically, there was an effort to improve the consistency of roller passes to obtain a more consistent coverage of the desired number of passes on the asphalt pavement being compacted. For each project, the contractor would inform the research team about the target number of passes desired.

On a typical project, the IC roller was used as the breakdown (or first) roller directly behind the paver. Typically, a before/after comparison was performed. This was accomplished by installing the IC components (including the on board display) on the roller and then collecting roller pass data both initially while the roller operator was not allowed to use the display (before) and then the roller operator was allowed to use the display after a training session (after). Figure 3 shows the results of the before and after experiment on the Indiana ICPF project. Note that the desired number of passes was obtained more uniformly with the use of the display, which will likely result in decreased variability of density. The roller operator was able to get a much more consistent number of passes by using the on board, color coded display. The reason for the improvement is that the operator was able to clearly view (in real-time) a color coded map of the rolling process. The conclusion that was reached was that the color coded-on board display required on IC rollers is an extremely valuable tool for roller operators.

Conducting Statistical and Geospatial Analysis of IC data

A major challenge in effectively using IC technology that utilizes GPS-based documentation systems is dealing with the massive amount of data that is produced. This was found to be a barrier to implementation in the early stages of the ICPF research. IC data collected on a project are often extremely large and new to both DOTs and industries. Thus, it requires practical guidelines and protocol to assist DOTs and industries to properly manage the IC data in order to provide support for decision-
making and QC/QA. Through the ICPF, the IC Data Management Guide (11) was developed to fulfill the above requirements. This document also provides guidelines for viewing and export of vendor-specific IC data in order to make use of a third party, independent IC data viewer tool for standardized analysis and reporting.

A software program named Veda (12) was developed that is designed to manage and evaluate IC data. Veda (pronounced as “Vehda” - means “knowledge”) is a generic software for viewing and analyzing geospatial data (Veda software homepage). Veda is developed by the Transtec Group with partial funding from the FHWA and MnDOT. The applications of Veda are geared toward intelligent compaction and sonic test rolling. Veda can now import data from various intelligent compaction machines and sonic test rollers to perform viewing, analysis, and reporting. This software is a great first step in addressing one of the biggest barriers to IC implementation, which is a myriad of issues related to handling the massive amount of data that is produced during the compaction process. Because it was developed through a research project, the data analysis software is available to all users (13).

An example of the Veda viewing feature is in Figure 4 for the Sakai IC mapping data from the Maryland HMA ICPF demonstration project. An example of the Veda analysis feature is in Figure 5 that displays a “compaction curve” (compaction index vs. roller passes) of the Sakai HMA IC data from the Indiana ICPF demonstration project. Veda software was used extensively during the ICPF projects and it is increasingly in widespread use by DOTs and contractors on HMA projects.

CASE STUDY

In this section of the paper, through a case study of the Wisconsin ICPF projects, the authors will illustrate the potential benefits of using Intelligent Compaction technology to improve QC on HMA paving projects. On the Wisconsin project, IC was used for a portion of the project while the research was being conducted. By building on the findings of the study, it can be illustrated how the effective use of IC for the entire project could have resulted in a longer lasting asphalt pavement.

The ICPF project in Wisconsin was performed in May 2010 on a HMA overlay over rubblized existing Portland cement concrete (PCC) pavement project near Mosinee WI. The test site is located on IH 39 at the junction of IH 39 and 153. The length of the project is about 5 miles with two lanes in the SB direction. The existing pavement is HMA on top of PCC slabs. During the demonstration, the existing HMA layer was milled and removed, then the PCC slab was rubblized or cracked-and-seated, before paving a 25mm HMA base followed by a 19mm second lift HMA intermediate layer and then a 12.5mm HMA surface, as shown in Figure 6. The full report of the Wisconsin ICPF project can be found on the Intelligent Compaction website (www.intelligentcompaction.com).

Two Sakai tandem drum rollers (SW 880 and SW 990) equipped with IC technology were used on this project. The SW 880 had 76 inch wide drums and the SW 990 had 84 inch wide drums. Both Sakai rollers had IC equipment and capabilities that meet the FHWA definition that were described previously in this paper. The Sakai IC rollers were used for mapping the rubblized concrete pavement and for compacting all three layers of HMA layers placed on top of the rubblized concrete pavement.

The ICPF team worked closely with the contractor to interface the research and construction activities. The contractor decided to produce two separate test sections with varying degrees of rubblization. One section was rubblized to obtain a well broken surface and the other was rubblized using less rubblization energy, which resulted in a much “coarser” surface texture and larger concrete pieces after rubblization. The former section was called the rubblized section and the latter section was called the “crack and seat” section. The Sakai SW 880 IC roller was used to compact the rubblized concrete in both sections in the vibratory mode, which allowed the collection of ICMV values on the broken concrete sections. Visually, the concrete transverse joints were very obvious. They appeared darker than other areas, which was probably due to underlying materials being pumped up in the joints over time. There were also some full-depth patches present in the existing concrete pavement. The purpose of the mapping was to evaluate the support characteristics of the broken concrete sections prior to paving with HMA. Interestingly, the “mapping” of the rubblized concrete seemed to clearly identify the weaker joints
through low ICMV values and stiffer areas with higher ICMV values where full depth patches were present. Examples of color coded mapping of both rubblized and “cracked and seated” sections are shown in Figure 7. Also, a statistical evaluation of the ICMV data obtained from both sections showed that the mean ICMV was higher on the crack and seat section (average CCV = 18) than on the rubblized section (average CCV=14). Since better support would be expected in the crack and seat section, this seemed to validate that ICMVs were sensitive to the difference in degree of rubblization.

It is thought that this was the first project in the United States where IC technology was used on a concrete pavement rubblization project. Since the highway industry has been searching for a viable and accurate QC tool for the rubblization process, the possible application of IC technology for the rubblizing process is intriguing.

The major findings of the WI ICPF project are as follows:
• Tandem drum IC rollers can be used effectively to map the rubblized and crack-and-seat PCC bases prior to the paving of HMA layer
• IC mapping of the rubblized and crack-and-seat PCC bases and soil shoulder was shown to be crucial in identifying the pavement conditions prior to the paving of the HMA layer (see CCV maps below)
• The IC roller can track the roller pass numbers, roller speeds, HMA surface temperatures, and the RMVs, which provides important metrics for the compaction quality;
• With the real-time information of IC roller passes, HMA surface temperatures and RMVs displayed on the screen, the roller operator can adjust rolling patterns to improve the compaction quality.

Summary - Wisconsin Case Study
IC technology was used for only a portion of the WI ICPF project. However, based on the findings during the research, some assumptions can be made about the benefits to this or a similar project if IC technology had been used for the entire project. It is apparent that the use of IC would have dramatically improved the QC process if used in various phases of the work. Specifically, IC technology could be used to identify areas of insufficient support from existing rubblized PCC pavement, to improve the compaction process by allowing the roller operator to apply a uniform number of passes and to help ensure that quality was being achieved by performing a statistical analysis of IC data.

The mapping did a surprisingly good job of clearly identifying the limits of soft spots in the rubblized PCC (mostly at joints). By using IC for a QC tool after the rubblization process, Wisconsin DOT or the contractor could have used that data to identify the limits of areas in need of repair. Repair of the soft spots would have resulted in improved and more uniform support for the compaction operation, which almost certainly would improve the density of the subsequent HMA layers.

It was demonstrated on this and other projects that the on board, color coded displays provides roller operators with a valuable tool that allows them to view (in real time) the compaction process during daylight and nighttime construction periods. This has been conclusively shown to result in more uniform and consistent numbers of the optimum passes being placed on the materials being compacted. Thus, IC provides a valuable tool for improving the compaction process.

And, finally, it is likely that by collecting and analyzing the IC data during the course of the projects, the contractor could improve QC by gaining valuable insight into the quality of their operation that is independent of the quality measures used in the QA process. This insight would allow the contractor to improve their QC operations and obtain a longer lasting pavement.

CONCLUSIONS
This paper has described how Intelligent Compaction technology can be used as a valuable tool for improving the QC of HMA projects. Using IC can benefit both the owner/agency and HMA contractor as IC addresses some of the major shortcomings in conventional equipment and processes. These new IC tools include on-board, color-coded displays, capability to measure underlying materials
support prior to paving and capability to collect data for statistical analysis of the effectiveness of compaction operations (10).

As part of the ICPF, a software program named Veda was developed that is designed to manage and evaluate IC data. This software is a great first step in addressing one of the biggest barriers to IC implementation, which is a myriad of issues related to handling the massive amount of data produced during the compaction process. The Veda software is available to the public.

A case study of the Wisconsin ICPF research was described to demonstrate how IC can improve QC of HMA paving. The project consisted of a two-lift HMA overlay on rubblized concrete pavements. Based on the ICPF findings, it can be concluded that Intelligent Compaction could have been used to improve QC in the following ways if it had been used effectively for the entire project:

1. Provide a tool to evaluate the concrete pavement rubblization process while it was underway. By measuring ICMV with the IC roller after rubblization and analyzing the collected data, the contractor could make decisions about the optimum degree of rubblization that needed to be performed.
2. Identify the limits of soft spots in the rubblized concrete pavement prior to placing the HMA overlay using IC mapping. This would have allowed the agency to make repairs to strengthen the soft areas identified at the joints in the rubblized concrete prior to paving.
3. Decrease variability in pavement density by improving the consistency of roller patterns during the HMA compaction operation by training the roller operator to use the on-board color-coded display.
4. Provide an independent analysis (separate from agency requirements) of quality by using Veda software to perform a statistical analysis of IC data.

At this time, there are some barriers to full implementation of IC technology as a QC tool by highway agencies. The major barriers are:

1. Availability of equipment that meet the FHWA criteria of IC equipment, which includes GPS, ICMV and temperature measurement.
2. Complexity of data collection, management and analysis. While strides have been made in this area through the ICPF, improvements must be made to simplify this process, to standardize the data, to develop analysis software and to develop training for field personnel.
3. Acceptance by agencies and contractors to replace or augment existing QC practices.

It is recommended that IC be adopted by highway agencies for routine use as a QC tool. Agencies and contractors should consider demonstration projects to familiarize themselves with IC technology.

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DISCLAIMER

The contents of this paper reflect the views of the authors who are responsible for the facts and the accuracy of the information presented herein and do not reflect the official view or policies of the Asphalt Institute, the Federal Highway Administration, or the Transtec Group. The contents do not constitute a standard, specification, or regulation. Trademark or manufacturers names appear in this paper only to facilitate the discussion related to the process and does not constitute an endorsement by the Asphalt Institute, the Federal Highway Administration, or the Transtec Group.
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FIGURE 5. Analyzing IC Data with Veda Software.
Test bed 01M (5/10/2010)

Description
This test bed consists of mapping the existing soil and rubblized PCC base layer on the IH 39 SB passing lane. The surface HMA was milled and removed, then the PCC base was rubblized or crack-and-seat. The Sakai SW880 double-drum IC roller was used to map the both the existing soil and rubblized PCC surfaces. The purpose is to evaluate the condition of the existing support prior to the asphalt construction.

FIGURE 6: Photos of Milling, Rubblization Equipment and Rubblized PCC.
FIGURE 7: Color-coded mapping of Rubblized PCC (left) and Crack and Seat PCC (right).