Toward Post-Digital Era: A Brief History of ISIC

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Abstract. In the last 20 years, the digital era of construction has been driven by 3D design/modeling, automation technologies, internet-of-thing, mapping, visualization, etc. Even though the Intelligent Compaction (IC) and Continuous Compaction Control (CCC) technologies have existed since 1976, IC/CCC has not penetrated the routine construction of infrastructure worldwide. The IC implementation in the United States (US) started in the early 2000s and accelerated during the IC Transportation Pooled Fund Study from 2007 to 2012. Through the following years, numerous technical and institutional issues and obstacles have hindered the progress of IC implementation at various stages. The US responded to these issues and obstacles through coordinated team efforts among the US FHWA, US States Departments of Transportation (DOTs), consultants, and IC manufacturers/solution providers. The new momentum takes IC to the following levels by integrating and leveraging IC with other emerging Intelligent Construction Technologies (ICT). This paper summarizes the development/implementation, issues, and solutions of IC/CCC, followed by the ICT expansion to a global platform and advancing ICT toward the post-digital era. This document is considered a brief history of the International Society for Intelligent Construction (ISIC).

Keywords: Post-digital era, Automation, Intelligent compaction (IC), Continuous Compaction Control (CCC), Technical Development, Implementation, International Society for Intelligent Construction (ISIC), Intelligent Construction Technologies (ICT).

1 Introduction

Intelligent Compaction (IC) and Continuous Compaction Control (CCC) technologies have existed for more than 40 years. However, the industry has not yet used IC/CCC in the routine construction of infrastructure worldwide. Even though the IC implementation in the US started in the early 2000s, it accelerated due to a Transportation Pooled Fund Study from 2007 to 2012. Since then, the US IC industry has become arguably a prominent market for IC. Throughout the IC implementation in the US, numerous issues and obstacles have hindered its progress at various stages. However, these issues and obstacles have been partially or fully addressed through coordinated efforts among the US Federal Highway Administration (FHWA), Staes Departments of Transportation (DOTs), the research community, and IC manufacturers/solutions providers. This paper summarizes the above issues and solutions as a model for successful IC implementation. This paper can also be considered the brief history of the International Society for Intelligent Construction (ISIC).

2 IC Implementation in the US

The timelines and milestones for IC efforts in the US are shown chronologically in **Fig. 1**. There were only limited CCC research studies by universities before 2004 in the US (e.g., Mooney et al., 2002). Between 2004 and 2005, the FHWA produced a roadmap for IC implementation after a SCAN tour in Europe. That document that coined the term "Intelligent Compaction" sparked interests in IC implementation at several, but limited, DOTs (Horan et al., 2004). Between 2007 and 2010, the National Cooperative Highway Research Program (NCHRP) commissioned a soil IC research project to guide field calibration and initial attempts for IC specification development (Mooney et al., 2010). During the same timeframe, the FHWA produced a prototype system for asphalt IC application, called Intelligent Asphalt Compaction Analyzer (IACA), based on the neural network technique. (Lemon 2011), along with a demonstration pooled fund study to accelerate the implementation of IC for soils, subbase, stabilized base, and asphalt materials. The momentum of the US national IC implementation started to build up during this period. (Chang et al., 2012),

Since 2007, a website (www.IntelligentCompaction.com) has provided a one-stop-shop for IC that has been updated continuously (Chang, 2007). The IC website was later included under the ICT website (www.IntelligentConstruction.com) (Chang, 2019)

The first FHWA IC specification for soils and asphalt was published on the IC website (Chang 2007) as guidance for US DOTs to develop their specifications. That guide specification included an IC system definition requiring a survey-grade GPS, accelerometer-based ICMV, non-contact temperature sensors (for asphalt compaction), and an onboard display of real-time color-coded maps of measurements (such as pass count, surface temperatures, ICMV, etc.).

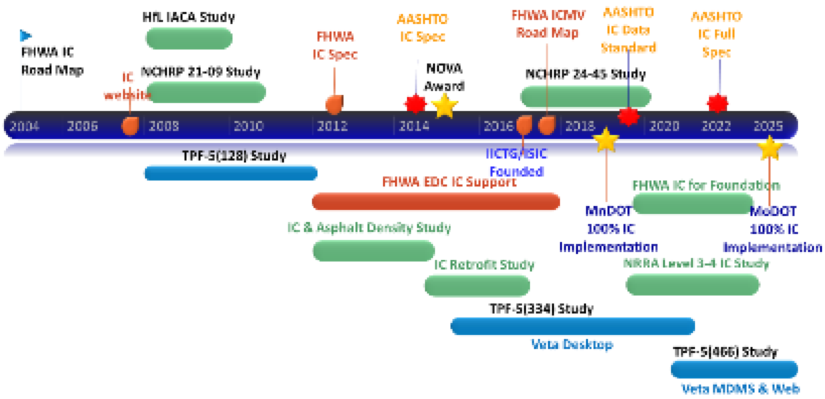

Fig. 1. Timeline and Milestones of IC Implementation in the US. (Chang, 2022)

Between 2012 and 2014, an FHWA study investigated the relationship between the intelligent compaction measurement value (ICMV) and asphalt in-place density. This study produces an IC-based stochastic model for asphalt in-place density prediction. (Chang et al., 2012). The Construction Innovation Forum presented the FHWA IC team with a NOVA Award to recognize the values and impacts of IC on the construction industry. In the same timeframe, Nazarian et al. (2015) conducted a study funded by FHWA to evaluate IC retrofit systems and provide guidelines for IC retrofit instrumentation and associated field calibration. The first American Association of State and Highway Transportation Officials (AASHTO) IC specification for soils and asphalt was published as a guide specification for state DOTs. (AASHTO, 2018). The first AASHTO standard data format specification for ICT was published in 2019 to facilitate IC data exchange. (AASHTO, 2019). The AASHTO IC specification for soils and asphalt officially became a standard in 2022 (AASHTO 2022).

From 2013 to 2017, the FHWA Everyday Counts (EDC) IC support project provided DOTs and industry technical support for implementing IC with numerous training workshops, equipment demonstrations, and phone/email/online support. This effort further accelerated the US national IC implementation. As shown in **Fig. 2**, 33 state DOTs out of 50 were interested in IC implementation, and seven states initiated their IC efforts. Among the States, California, Minnesota, and Missouri were considered US national leaders.

The International Intelligent Construction Technologies Group (IICTG) was founded to take IC to higher levels by integrating IC with other intelligent construction technologies (ICT). (Chang 2016). IICTG was renamed as International Society for Intelligent Construction (ISIC) in 2019 to expand its global reach (Chang 2019).

The NCHRP Project 24-45 aimed to produce the methods to measure layer-specific mechanical properties (such as modulus and stiffness) with IC. That study paved the road for using ICMV to accept compaction in the future (NCHRP 2019).

The FHWA Tech Brief on ICMV Road Map was published to guide ICMV classification and future development. (Chang 2017), while the Minnesota Department of

Transportation (MnDOT) had reached 100% IC implementation with a staged approach in 2014.

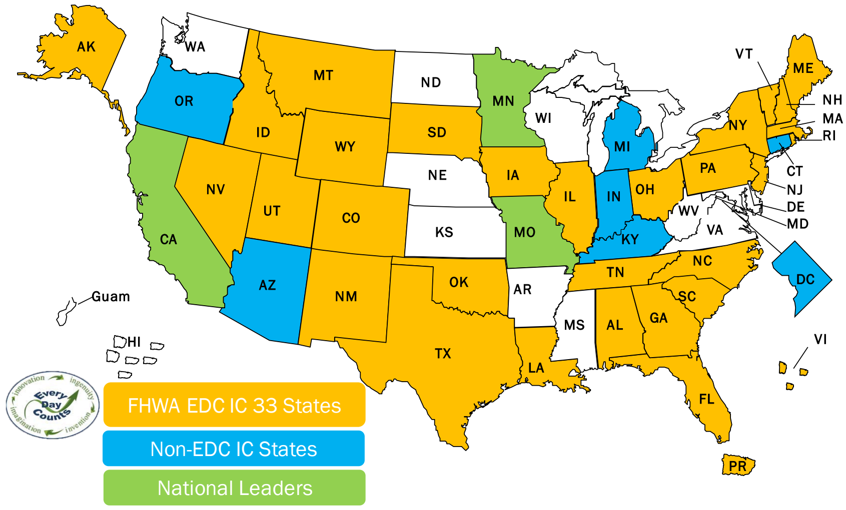

Fig. 2. IC National Implementation Status in the US since EDC 2 as of 2014. (Chang, 2020)

The pooled fund study TPF-5(334) titled the "Intelligent Construction Data Management (ICDM) - Veta" provided guidance and continuous funding to enhance the AASHTO standard Veta software tool to meet US DOTs and industry's needs for standardization and data management. (TPF-5(334) 2015-2020) Veta has become the de facto public-domain ICT tool in the US and is increasingly used by the industry for the rest of the world.

In 2019, FHWA sponsored an IC research study on the feasibility of using IC to ensure the suitability and uniformity of foundation layers for asphalt and concrete pavements. NRRA also sponsored an IC study to evaluate Level 3-4 ICMV and develop a roadmap for future IC certification.

Starting in 2021, the pooled-fund study TPF-5(466) "National Road Research Alliance – NRRA (Phase-II)" continues to support the ICT advancement in the US. Notably, it sponsors a significant enhancement of Veta to support the Materials Delivery Management System (MDMS) standard platform and web conversion.

3 Issues and Solutions for the US IC Implementation

As shown in **Fig. 3**, during its IC implementation history, the US has faced the following issues at different stages:

- Stage 1 - Specification: IC specification was the main driving force to kick start IC implementation and stimulate IC innovation.

- Stage 2 - Equipment Supplies: Once the IC implementation started, the IC equipment supplies posed the first hurdle to overcome.
- Stage 3 - Technology Transfer and Training: As IC continues to be increasingly used by the industry, the needs for technology transfer and training are mounting. The buy-in and support from the upper management of owners and agencies are also crucial to moving IC implementation forward.
- Stage 4 - Data Quality Assurance (QA) and Management: As IC implementation becomes widespread, the data QA and management for data storage, transfer, analysis, and reporting are the final obstacles for IC implementation.

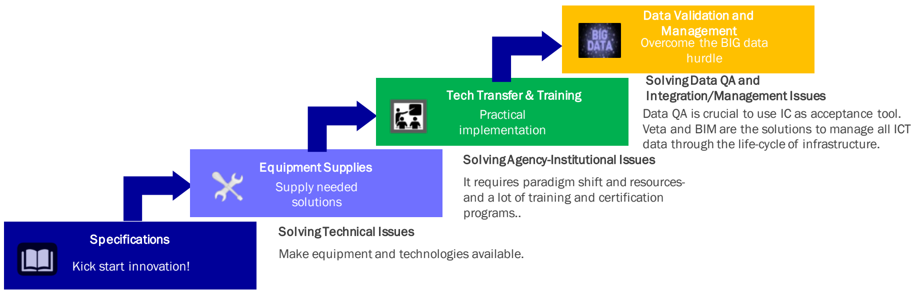

Fig. 3. Overcome IC-related Issues at Different Stages in the US. (Chang, GK (2020))

The momentum for IC implementation relies on advanced science and technologies and coordinated efforts among stakeholders, academicians, practitioners, and industry solution providers. Without a sound implementation plan or roadmap, the direction of technological advancements may be stagnated or be steered in the wrong direction. Without the involvement of practitioners and industry solution providers, the road map may lead to nowhere. Without the specifications from stakeholders and agencies, the practitioners and industry solution providers will not have the incentive to move forward. Without technological advancements, the demands from the stakeholders and industry will not be met.

The following sections detail the sources of issues and corresponding solutions for different stages of IC implementation in the US.

3.1 Stage 1 Issue – IC Specifications

The following items are the main issues related to IC specifications:

- Lack of IC specifications: The kick-start of IC implementation requires IC specifications that are driven by the industry and manufacturers alone but .are endorsed by owners and agencies.
- Inconsistent IC specifications: The inconsistency of IC specifications among different DOTs may cause challenges and difficulties for IC supplies in meeting the requirements of different DOTs.
- Lack of IC data exchange/storage standards: It is difficult for various owners-agencies and contractors to manage and share IC data without IC data.

The following solutions have been provided to solve some of those concerns:

- National Guidelines/Standards: The US FHWA IC standards were published in 2012 as an umbrella guide specification for DOTs. The 2017 AASHTO IC provisional standard and the 2019 AASHTO ICT data standard are more elaborated IC standards. In 2022, the AASHTO provisional IC standard becomes an official specification.
- Local/State specifications: More than half of US DOTs (i.e., around 25 States) have developed their IC specifications (**Fig. 4**), primarily for asphalt IC. The popularity of the asphalt IC vs. soils IC may be due to the industry understanding that IC is a suitable tool in ensuring uniform roller passes and coverages within the desired temperature range. These specifications have driven the increasing number of IC projects in the US (**Fig. 5**), dated up to 2017. Since 2018, the growth of IC projects in MN and MO has outpaced other DOTs, partly due to their declared goals for full IC implementation for all highway projects.
- Agency-Industry Committees: Many DOTs have formed agency-industry working groups to develop and refine IC specifications.
- Agency initial investment: Many DOTs were willing to pay for the IC cost for initial projects, overcoming IC implementation's initial obstacle.

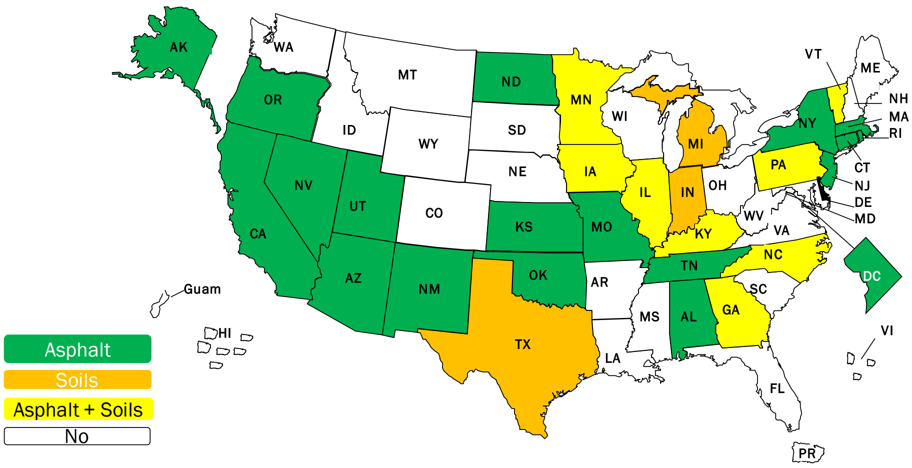

Fig. 4. Types and Distribution of US DOT IC Specifications. (Chang, GK (2020))

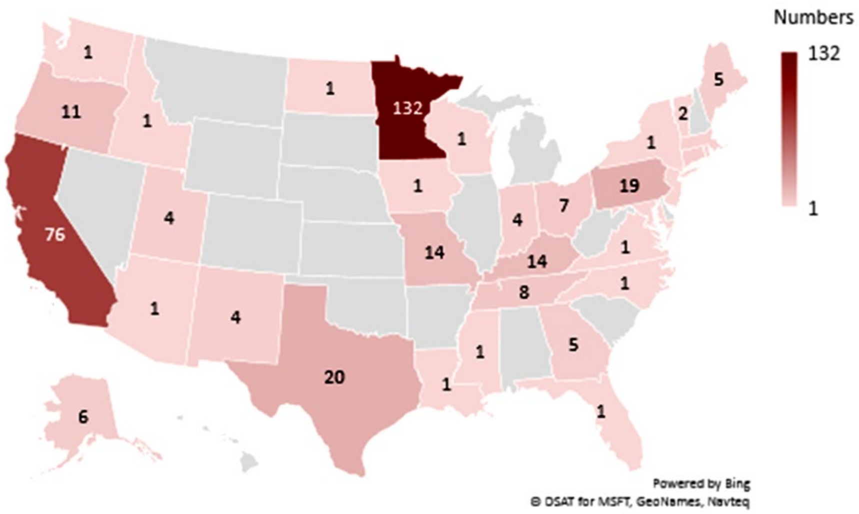

Fig. 5. Distribution of Accumulated Number of IC Projects in the US between 2007 and 2017. (Chang, 2020)

3.2 Stage 2 Issue - Equipment Supplies and Technical Support

The main issues related to equipment supplies and tech support can be categorized in the following manner:

- Lack of IC equipment supplies: Most construction equipment dealerships have little IC equipment to provide to the local industry early. It is a typical chicken-and-egg issue.
- Lack of equipment dealers/technical supports: Most dealerships of construction equipment dealers and technicians have no or little IC training and field experience to provide technical support at the early stages.

The following solutions have been devised within the US:

- Tackle the chicken-and-egg issue: Supply-and-demand that drives the IC market is a constant battle. The issue has been gradually resolved over the years since 2008.
- Vendors ramp up equipment supplies: IC vendors and dealers started to stock IC equipment and trained their dealers/technicians as the market demand increased. Due to market demands, IC vendors have ramped up national technical support and local dealership training.

3.3 Stage 3 Issue – Agency-Institutional

The following items are the main items related to agency-institutional issues:

- Lack of buy-in of upper management and districts: It is crucial to have leadership's buy-in and support for any owners-agencies to kick-start and continue IC implementation. The upper management of owners/agencies generally lacks knowledge of the IC technologies and their benefits.
- Lack of personnel and resources: As owners-agencies start IC projects, they would immediately face the lack of personnel to manage IC projects.

The following solutions have been devised within the US:

- Benefit-oriented executive summary: Significant efforts have been focused in the US to provide a benefit-oriented executive summary presentation to executive levels to get their buy-in, who are, in turn, influential in driving the IC implementation at agencies. An example of such an effort was the seven EDC Summits conducted in the US in late 2012.
- Seek (initial) consulting support: Consulting support is helpful to bridge the gap of the lack of resources at agencies (e.g., Missouri Department of Transportation hired consultants to produce IC protocols, to revise IC specification to manage/support IC field projects, to produce annual reports, to conduct annual DOT-industry meeting, and to present an executive briefing to the DOT executives.).
- Assign dedicated personnel: Agencies have assigned dedicated personnel and resource to facilitate the IC implementation (e.g., MNDOT).
- Create new dedicated positions: Agencies have created new positions and resources to manage the IC implementation (e.g., Advanced Materials and Technology Engineer by MNDOT).
- Train agency personnel: Agencies started to train their personnel to manage IC projects.

3.4 Stage 3 Issue –Technology Transfer and Training

Once the IC equipment supply issue is resolved, the next issue is training dealer/technical support to overcome numerous failures in the fields at the early stages. The following items are the main items related to technology transfer and training:

- Lack of training for dealers/technical support:
- Lack of training for industry
- Lack of training for agency

The following solutions have been devised within the US:

- The IC vendors have ramped up training for dealers and the industry.
- The IC dealers have ramped up training for industry and agencies.
- US FHWA has sponsored numerous IC workshops around the US since 2008.

Consultants can bridge the gap of training for the agencies and industry. Between 2013 and 2017, a consultant hired by FHWA provided phone and online IC support nationally, delivered more than 50 Intelligent Compaction Data Management (ICDM) – Veta workshops (**Fig. 6**), and Intelligent Compaction Equipment Demonstration

(**Fig. 7**). The FHWA has also published tech briefs to answer any questions on whether and when IC pre-mapping can be applied (**Fig. 8**), to address the visual interpretation and color-palette settings of color-coded IC maps (**Fig. 9**), to describe the elements of IC specifications, and to establish a roadmap for ICMV (**Fig. 10**.). The FHWA has also published applications notes on IC for soils and HMA compaction to demonstrate how DOTs and contractors use IC for embankment and asphalt compaction (**Fig. 10**)

Fig. 6. FHWA Sponsored More Than 50 Intelligent Compaction Data Management (ICDM) – Veta hands-on workshops around the US from 2012 to 2017. (Chang, GK (2020))

Fig. 7. FHWA Sponsored More Than 50 Intelligent Compaction Equipment Demonstrations around the US from 2012 to 2017. (Chang, GK (2020))

Fig. 8. FHWA Published Intelligent Compaction Tech Brief on IC Pre-Mapping and Color-Coded IC Maps.

Fig. 9. FHWA Published Intelligent Compaction Tech Brief on IC Specifications and Intelligent Compaction Measurement Values (ICMV) Road Map.

Fig. 10. FHWA Published Intelligent Compaction Application Notes on IC for Soil Compaction and HMA Compaction.

3.5 Stage 3 Issues - Certification

The following items are the main items related to certification:

- Lack of certification for IC Quality Control (QC) managers and technicians: As DOTs start to require IC in their specification, the need for qualification/certification of contractors' personnel to perform IC-related work, such as set-up of IC equipment and management of IC data.
- Lack of certification for equipment: As an FHWA requirement, equipment and operator certification is needed if the collected data is used for items such as incentives and disincentives.

The following solutions have been devised within the US:

- The certification or qualification for IC QC managers and technicians has begun in several state DOTs (e.g., California, Missouri, and Minnesota) to ensure IC projects are adequately performed and managed by qualified personnel.
- As of 2020, there are no IC equipment certification programs in the US. The ongoing research "Evaluation of Level 3-4 ICMV," sponsored by the National Road Research Alliance (NRRA), is expected to deliver a roadmap for IC equipment certification in 2022.

3.6 Stage 4 Issue - Field Data Validation

The following items are the main issues related to field data validation:

- Lack of practical field validation for Global Navigation Satellite System (GNSS) and Global Position System (GPS): Even though accurate and precise positioning is crucial for valid IC data, there was a lack of standard procedures in IC specification at the US's early stages of IC implementation.
- Lack of IC data QA (i.e., IC temperature measurements and roller passes) to meet the US federal requirements: The US federal government requires independent data validation for federally funded projects if the data have to be used for incentive or disincentive. There was a lack of such QA procedures in US IC specifications.

The following solutions have been devised within the US:

- Practical procedures for field validation of GNSS/GPS with a target tolerance were developed and incorporated in the FHWA and AASHTO IC specifications. The procedures allow the IC system to be initialized and compare the IC GNNS/GPS measurements and hand-held rover measurements.
- Initial practical procedures to validate temperature measurements and roller passes have been developed and validated in the field by a pooled fund study and some US DOTs (e.g., MODOT) since 2019. MoDOT uses GPS trackers mounted independently on IC rollers to track their positions. The data from the GPS trackers were then gridded and used to compare with the IC pass counts. No known IC temperature data QA process is available due to the complexity of measurement conditions (including roller movements, angles of temperature sensors, and the moisture on the surfaces). More results and recommendations are anticipated from those studies for independent validation of IC data for QA.

3.7 Stage 4 Issue – IC Data Management

The following items are the main issues related to IC data management:

- Lack of public domain software for IC data management: All IC vendors have their data formats and management software that pose challenges to developing bid items by owners-agencies and contractors.
- Lack of life-cycle data management of infrastructure: Once IC data are collected and analyzed, the value may be limited if not used in infrastructure life-cycle management.

The following solutions have been devised within the US:

The US FHWA sponsored the development of a geospatial software package, Veta, as a public-domain IC data management tool. Veta has been continuously enhanced since 2013 is included in the AASHTO R 110 Paver-mounted Thermal Profiles (PMTP) standard and R 111 IC standard. The use of Veta has dramatically facilitated IC data management and training in the US. Veta has also been used to resolve IC data loss and mismanagement issues with automation using the direct-download-from-the-cloud feature (**Fig. 11**).

The rise of Building Information Modelling (BIM) has provided a potential facility to leverage the value of IC data from the as-built sources and integrate it with planning, design, operation, and maintenance stages of the life-cycle for infrastructure. In

2022, the NRRA has sponsored the further development of Veta to implement the AASHTO provisional Material Delivery Management System (MDMS) and conversion of Veta Web. This effort has elevated the ICT values to the entire construction industry by fusing all ICT data and sharing it with agencies and AASHTOWare (**Fig. 12** and **Fig. 13**) (Turgeon and Embacher, 2022).

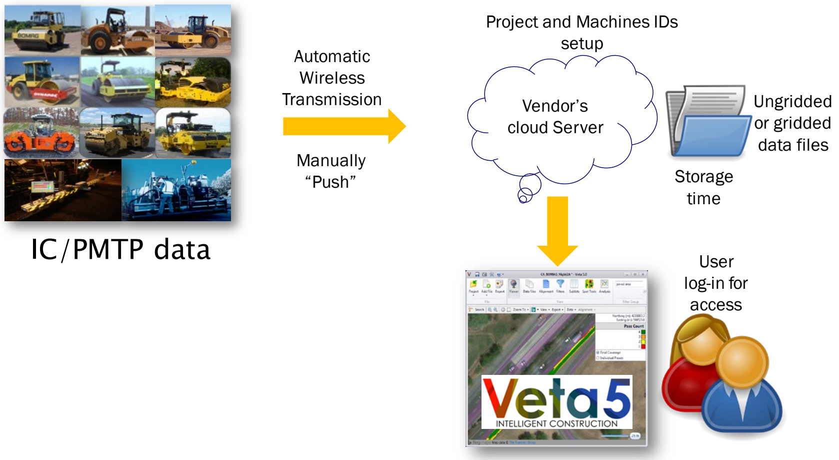

Fig. 11. IC Data Flow for Direct Download from the Cloud into Veta. (Chang, GK (2020))

Fig. 12. MDMS and Veta Web to implement virtual roadways and BIM. (Turgeon and Embacher, 2022)

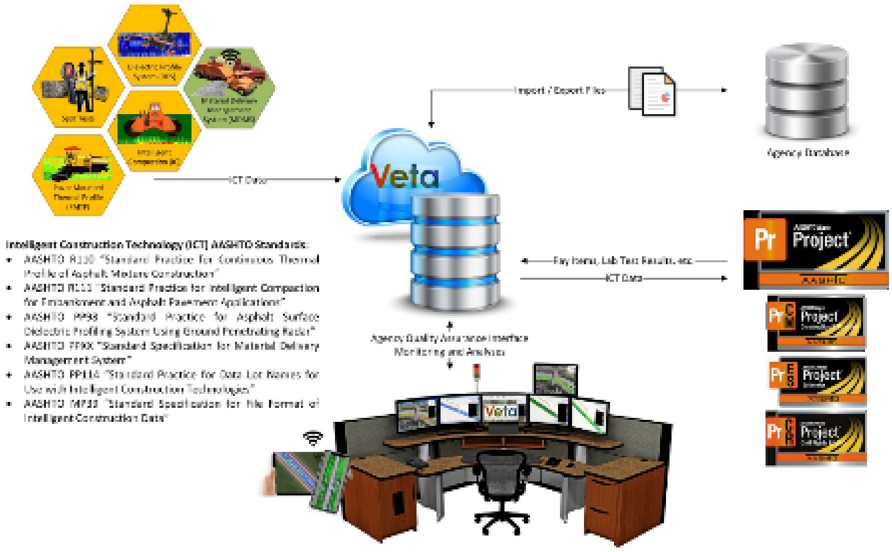

Fig. 13. ICT Data Flow of MDMS and Veta Web (Turgeon and Embacher, 2022)

3.8 Stage 4 Issue - ICMV Levels

The following items are the main issues related to ICMV levels are:

- Lack of Level 3-4 ICMVs: The US FHWA IC Roadmap (**Fig. 14**) defines five levels of ICMV. The Level 3-4 ICMV requiring a high-performance IC system is still unavailable in the US.
- Lack of Level 5 ICMVs: Ultimately, the Level 5 ICMV would provide the holy grails of compaction measurement expressed in density and modulus. However, such a commercial product is not available yet.

The following solutions have been devised within the US:

- As mentioned previously, the ongoing NRRA Level 3-4 ICMV Evaluation study has been initiated to evaluate the Level 3-4 ICMVs. The outcome of that study will help the industry manufacture more Level 3-4 ICMV systems and produce a plan for future IC certification.
- Level 5 ICMV is under research and development to combine the mechanical ICMV measurement systems with artificial intelligence (AI) and deep learning) to make IC a mechanistic tool.

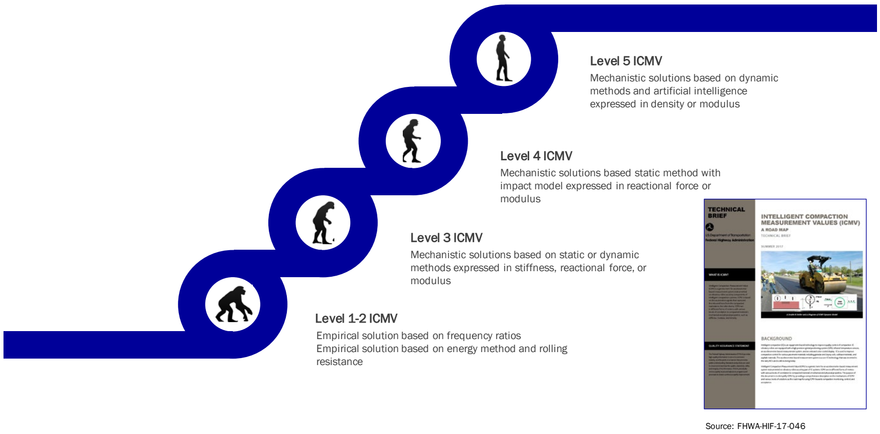

Fig. 14. The Classification System of ICMV from the US FHWA Tech Brief – ICMV Road Map (2017) (Chang, 2020)

4 Outreach to the World

With the initial success in the US described in the above sections, the former FHWA IC team members and ISIC leaders have outreached to other countries in North America, Europe, China, Japan, and Australia to assist in local agencies and industry for their IC implementation.

4.1 Outreach to Sweden, Australia, Japan, and China

The co-author, Dr. George K. Chang, has spoken on IC implementation in Sweden for the Swedish Asphalt Days in 2017 to help to generate more interest in the Swedish industry. (**Fig. 15**) Although IC/CCC was invented in Sweden in the 1970s, its implementation has been limited.

Fig. 15. US IC Outreach to Sweden (2017) (Source: Chang, GK (2017))

The co-author, Dr. George K. Chang, conducted the first IC workshop in Australia for the Australian Geomechanics Society in 2018. (**Fig. 16**) The IC implementation in

Australia has since built on momentum. The industry has started using IC compaction in multiple highway projects and the ongoing Western Sidney Airport construction. The local agencies also sponsor studies such as the TMR P105 research program, WA Road Research & Innovation Program (WARRIP), etc. WestRoads have since conducted open houses, developed their IC specifications, and started pilot field projects. Though slowed by the impacts of COVID-19, those IC implementation efforts are expected to resume in 2022. An academic such as the SPARC Hub has initiated several IC research projects, such as the IC benefit study. The Austalia Flexible Pavement Association (AfPA) also fully supports IC training and implementation in Australia.

Fig. 16. US IC Outreach to Australia (2018) (Chang, GK (2018))

The co-author, Dr. George K. Chang, and Prof. Soheil Nazarian conducted the first IC workshop in Japan for the Japanese Society of Civil Engineers in 2019 to boost the interest in IC implementation. (**Fig. 17**) One of the major IC manufacturers, Sakai, was in Japan starting in the 1990s, but their implementation has been limited.

Fig. 17. US IC Outreach to Japan (2019) (Source: Chang, GK (2019))

In China, the co-author, Prof. Guanghui Xu has been conducting IC research and implementation since the 1990s. The timeline is summarized in **Fig. 18**. Prof. Guanghui Xu published an IC monograph in Science Press and China Railway Press. Since 2011, Prof. Xu presided over the compilation of China's first IC standards and product standards, including a railway industry standard (2011), a railway enterprise standard (2015), a highway industry standard (2017), a standard for Hebei Province (2017), and a standard for Heilongjiang province (2021). (**Fig. 19**) The co-author, Dr. George K. Chang, has advised the latter three standards.

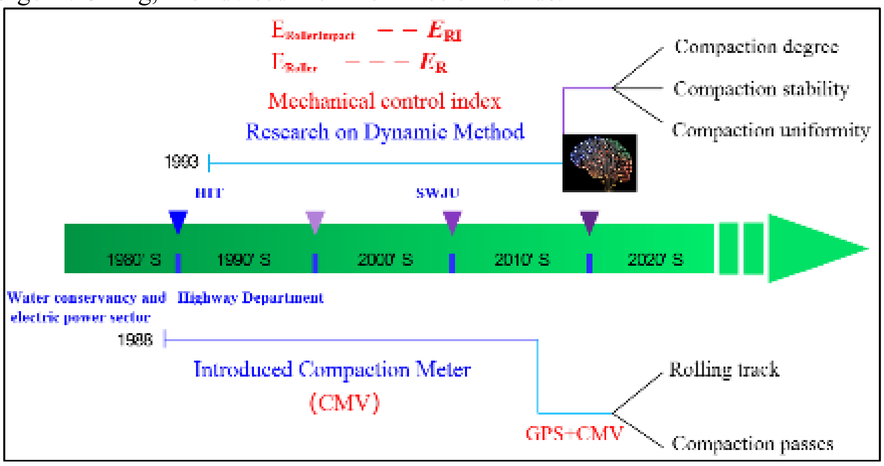

Fig. 18. China IC Timeline (Source: Xu (2021))

Fig. 19. China IC Standards (Source: Xu (2021))

4.2 US IC Expert Task Group

The US Intelligent Compaction Expert Task Group (ETG) was formed unofficially by Dr. George Chang (the co-author) and Mr. Antonio Nieves of FHWA in 2012. The IC ETG members include FHWA, DOT, vendors, industry, and consultants for about 65 members from the US and worldwide. This ETG has conducted one to two face-to-face meetings per year to focus on issues and solutions on technologies and implementation for IC (**Fig. 20**). This ETG was renamed the Intelligent Construction Technologies (ICT) ETG to broaden its scope to include other emerging innovations in 2018. The ICT ETG was merged into the ISIC North American Chapter in 2019. It is essential to show the lineage of the progress of IC into global ICT driven by the initial success of IC in the US.

Fig. 20. US IC Expert Task Group (ETG) (2013-2018) that was merged to the ISIC North America Chapter in 2019 (Chang, GK (2020))

4.3 Establishment of International Society for Intelligent Construction (ISIC)

With the momentum built by the IC ETG and ICT ETG, the International Society for Intelligent Construction (ISIC) was founded by Dr. George K. Chang (US), Prof. Antonio G. Correia (Portugal), Prof. Guanghui Xu (China), and Prof. Soheil Nazarian

(US) in 2016. ISIC was initially called as International Intelligent Construction Technologies Group (IICTG). IICTG was renamed ISIC in 2019 to broaden its global reach. The ISIC is intended to be the complete global source for knowledge and information on intelligent construction technologies for public agencies, contractors, consultants, academia, and other relevant industries. The following description extends the influence of the IC/ICT ETG to the world via ISIC activities.

Scope and Vision.

ISIC provides a forum for disseminating knowledge concerning collecting, analyzing, and applying information relating to intelligent construction technologies (ICT) for infrastructure. ICT is a combination of modern science and innovative construction technologies. The mission of ISIC is to promote the applications of ICT to the life-cycle of infrastructure: from the survey, design, construction, operation, and maintenance/rehabilitation by adapting to changes of environments and minimizing risks. The goals of its mission are to improve the quality of construction, cost-saving, and safety.

The scope of ISIC covers all current and emerging intelligent construction technologies for the life-cycle of infrastructure. The scope includes intelligent sensing, data analysis, decision-making, and execution. The scope covers civil engineering, construction machinery, electronic sensor technology, survey/testing technology, information technology/computing, and other related fields.

ISIC Committees

The ISIC executive committee consists of the founding members of IC described above to provide visions and leadership for the ISIC global members and ICT industry. (**Fig. 21**)

Fig. 21. ISIC Executive Committee Members. (Source: Chang, GK (2020))

The ISIC steering committee consists of ICT leaderships worldwide to guide ISIC plans and activities. (**Fig. 22**)

Fig. 22. ISIC Steering Committee Members. (Source: Chang, GK (2020))

The ISIC technical committee consists of ICT experts in all subfields of ICT world-wide to provide ISIC technical plans, materials, and activities. (**Fig. 23** and **Fig. 24**)

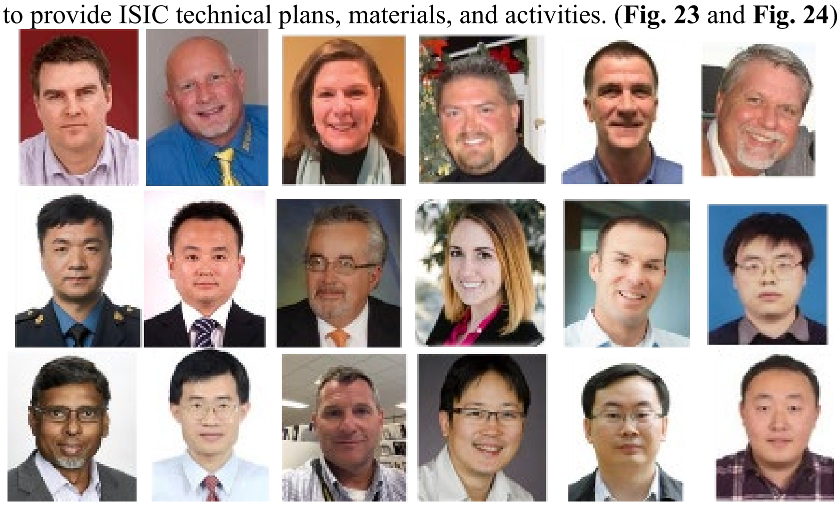

Fig. 23. ISIC Technical Committee Members (1 of 2). (Source: Chang, GK (2020))

Fig. 24. ISIC Technical Committee Members (2 of 2). (Source: Chang, GK (2020))

Nine sub-committees cover the overall scope of ICT and ISIC. The following descriptions summarize the specific scopes.

SC1-Theory and Application Subcommittee.

The scope of this committee covers the basic theory and applied research on intelligent construction-related fields. It includes mechanics (such as elasticity, wave, and vibration, viscoelasticity, fatigue, and fracture), engineering machinery, sensors/measurement technology, and intelligent algorithms, as well as related theories and applications.

SC2-Sensing Technologies and Equipment Subcommittee

The scope of this committee covers all relevant technologies for obtaining information, including sensor technology and equipment, measurement technology and equipment, data acquisition technology and equipment, Internet of Things, etc.

SC3-Information and Data Application Subcommittee

This committee's scope covers intelligent construction involving information and data-related technologies, including data science, signal analysis, cloud computing, information platforms, etc.

SC4-Artificial Intelligence Application Subcommittee

The scope of this committee covers the application of AI technology in engineering construction, including a variety of intelligent algorithms and techniques applied in the construction field sites, engineering expert systems, machine learning, and more.

SC5-Intelligent Design Subcommittee

The scope of this committee covers all relevant, intelligent technologies in the design phase, including CAD, BIM, VR/AR, AI, etc.

SC6-Intelligent Construction Subcommittee.

The scope of this committee covers all relevant technologies during the construction phase. Including material monitoring, paving and compaction monitoring, automated machine control (AMC), automatic mechanical guidance (AMG), autonomous engineering machinery (ACM).

SC7-Intelligent Maintenance Subcommittee

The scope of this committee covers all relevant, intelligent technologies in the maintenance phase, including a variety of non-destructive testing technology and equipment, evaluation, and decision-making technology.

SC8 - Education and Training Subcommittee

The scope of this committee is to promote globally intelligent technologies, including textbooks, technical training, and so on.

SC9-Integrated Technology Subcommittee

The scope of this committee covers relevant technologies not covered by the above professional Subcommittees. It includes a variety of boundary disciplines and technologies, innovative technologies with potential engineering applications.

ISIC Chapters

The ISIC Chapters are created to reach out and better serve local ISIC members and the ICT industry. The European Union Chapter is led by Prof. Antonio G. Correia of the University of Minho, Portugal (**Fig. 25**). Mr. Tim Kowalski of Wirtgen Group leads the North America Chapter (**Fig. 26**). The ICT ETG merged with the North American Chapter in 2019.

Fig. 25. ISIC European Union Chapter and Key Members. (Source: Chang, GK (2020))

Fig. 26. ISIC North American Chapter and Key Members. (Source: Chang, GK (2020))

Partners

The ISIC academic partners include universities and research entities worldwide to assist ISIC with their ICT research efforts (**Fig. 27**). The ISIC industry partners include significant manufacturers of ICT equipment and solutions worldwide to assist ISIC in practical ICT applications.

Fig. 27. ISIC Academic Partners. (Source: Chang, GK (2020))

ISIC International Conferences

The ISIC international conferences are conducted once every two years to provide a unique platform for all ICT professionals worldwide. The ISIC 2017 international

conference that was held in Minnesota in 2017 was a great success (**Fig. 28**). The ISIC 2019 international conference that was held in Beijing in 2019 continued expanding the success.
Fig. 29). The ISIC 2019 international conference report was also published (**Fig. 30**). The next ISIC international conference will be in Guimaraes, Portugal, in 2022 (this conference).

Fig. 28. ISIC 2017 Conference Participants in Minnesota, US, in 2017. (Chang, GK (2020))

Fig. 29. ISIC 2019 Conference Participants in Beijing, China, in 2019. (Chang, GK (2020))

Fig. 30. ISIC 2019 Conference Summary Report. (Chang, GK (2020))

4.4 Future Development of ISIC and Global ICT Efforts

The ISIC also plans for an ICT Journal, series of ICT textbooks, webinars, and lecturers-led training workshops. ISIC leadership is also planning to adapt to the post-COVID-19 era to provide further online workshops, online libraries, etc., on ICT education and promotion.

ISIC Webinars

The ISIC webinars are conducted once every two to three months to engage its members and friends. The topics of the ISIC webinars include Building Information Modeling (BIM) for Pavements, Automation in Construction, Introduction to ICT, New Digital As-Built and Project Information Modeling DAB/PIM), etc. (**Fig. 31**). All ISIC webinars are well attended. ISIC will also conduct webinars on various topics from the ISIC book series described in the next section.

Fig. 31. ISIC Webinars. (Source: Chang, GK (2021))

ISIC Book Series

A book series that aims to provide systematic ICT materials to universities and training professionals for ICT-related college courses and workshops is being developed. The book series will assist in preparing the next generations of the workforce for the ICT industry. The ISIC ICT book series titled "Intelligent Construction Technologies for Transport Infrastructure" includes the following manuscripts in Chinese and English (subject to change) (**Fig. 32**):

1. Introduction to Intelligent Construction Technologies for Transportation Infrastructure
2. Basis of Perception Terminals: Information Technology in Engineering
3. Basis of Perception Methods: One-dimensional Dynamics and Applications in Engineering
4. The Basis of Machine Analysis and Decision-Making: Into Machine Learning
5. A Weapon for Engineering Quality: Perception and Data
6. Executive Assistant: Control Technology in Engineering
7. Pioneer of Intelligent Construction: Intelligent Compaction

The authors consist primarily of ISIC members led by the ISIC Executive Committee. The publishers will include the Chinese Railway Publication Company and Elsevier for the Chinese and English versions. The Chinese version of Book No. 1 was published in November 2020, while its English version is expected to be published in 2022.

Fig. 32. ISIC's ICT Book Series in Chinese and English Editions. (Source: Chang, GK (2022))

Goals of the ISIC 5-Year Strategy Plan

Based upon the ISIC mission, vision, values, previous plan cycle accomplishments, and the current state analysis, ISIC periodically determines and defines strategic priorities. The ISIC 5-Year Strategy Plan (2020-2024) goals are summarized in **Fig. 33**.

Fig. 33. Goals of the ISIC 5-Year Strategy Plan. (Source: Chang, GK (2022))

5 CONCLUSIONS

This paper summarizes the history and the issues/solutions of IC implementation in the US and the establishment of ISIC by expanding the scope of IC to intelligent construction technologies. The keys to the success of IC implementation in the US can be summarized in the following manner:

- Passion: ICT champions within agencies or companies are fundamental driving forces.

- Patience: It takes time for IC implementation. A well-thought plan is a key to success.
- Communication: Forming Expert Task Groups among agencies, IC suppliers, earthwork/paving contractors, and consultants are crucial.
- Strategy: The strategy is to start with low-hanging fruits to minimize risks during IC implementation.

A good model for successful ICT implementation is the MNDOT's stage approach requiring IC for 100% earthwork and asphalt major paving projects. (**Fig. 34**) MODOT is anticipated to be the next US DOT to implement IC and PMTP by 2025 fully.

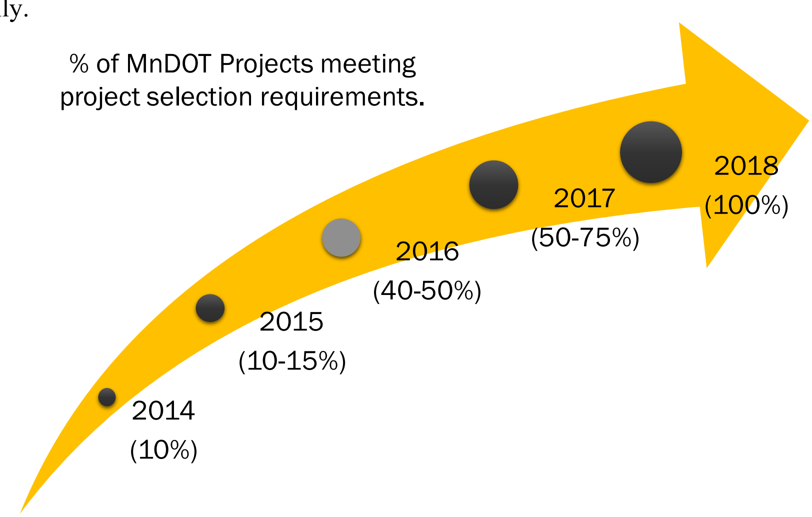

Fig. 34. The Staged IC implementation plan of MnDOT. (Chang, GK (2020))

This document shares the lessons learned during the US implementation with issues encountered and solutions responded. Though not intended to be duplicated outside of the US, these successful experiences would be valuable to other countries in the process or plan for ICT implementation. This document also demonstrates the expansion of IC into the global ICT advancement and implementation with the ISIC leadership and members worldwide. Ultimately, the authors would like the ISIC's visions as the path forward for the post-digital era.

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