Real-Time Smoothness: State of the Practice and Value Proposition

Final Report
December 2024

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16. Abstract

Real-time smoothness (RTS) is a valuable quality control tool for helping contractors improve the as-constructed smoothness of concrete pavements. The Second Strategic Highway Research Program (SHRP2) R06E project titled Real-Time Smoothness Measurements on Portland Cement Concrete Pavements During Construction helped to advance real-time smoothness measuring technologies through unbiased field evaluations and demonstrations and the development of a draft model specification and guidelines. In response to this study, the Federal Highway Administration (FHWA), through the SHRP2 Solutions Implementation Assistance Program, funded additional follow-up work to continue development and implementation, with the goal to eventually achieve routine use of real-time smoothness measuring technologies by owner-agencies and paving contractors. A key aspect of implementation efforts has been an equipment loan program that allowed owner-agencies and contractors the opportunity to evaluate RTS technology on active concrete paving projects using FHWA-owned RTS systems. The equipment loans were continued under the present cooperative agreement between FHWA and the National Concrete Pavement Technology Center. This report summarizes key findings from these implementation efforts through documentation of the current state of the practice and an explanation of the value proposition of RTS technology.

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REAL-TIME SMOOTHNESS: STATE OF THE PRACTICE AND VALUE PROPOSITION

WORK ORDER 6: NONDESTRUCTIVE TESTING AND REAL-TIME TECHNIQUES

Final Report
December 2024

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EXECUTIVE SUMMARY

Real-time smoothness (RTS) is a valuable quality control tool for helping contractors improve the as-constructed smoothness of concrete pavements. RTS technology is mature and widely used in the concrete pavement industry. RTS demonstrations through the equipment loan programs under the Second Strategic Highway Research Program (SHRP2) and Federal Highway Administration (FHWA) over the past 10 years have helped encourage contractor investment in RTS technology through evaluations of the systems and the data they provide during and after paving.

Three key benefits of RTS for helping contractors improve pavement smoothness identified through these implementation efforts include the following:

1. RTS provides a general idea of smoothness during paving, such that there are no surprises when the hardened pavement smoothness data are collected.
2. RTS allows the contractor to assess the impact of changes to paving processes on smoothness, including but not limited to changes in the concrete mixture and changes to paver operation.
3. RTS helps the contractor identify and mitigate systematic paving factors that appear in the pavement profile and affect smoothness results.

Because an RTS system is a construction quality control tool, the cost of ownership is borne by the contractor. However, the cost of an RTS system is minimal in comparison to the size of most concrete paving projects where it might be used, and with the majority of concrete pavement smoothness specifications nationwide providing incentive payment for high levels of smoothness, there is the potential to offset the initial cost of an RTS system with a single paving project. Furthermore, when factoring in the cost of corrective action such as diamond grinding or removal and replacement due to unsatisfactory smoothness, there is additional potential justification for investing in an RTS system.

While the financial benefits of using RTS will primarily be realized by contractors, the potential for improving as-constructed smoothness also benefits owner-agencies and the traveling public in the form of a long-lasting, smooth-riding pavement (Swanlund 2000). In addition, with pavement roughness being a primary contributor to excess fuel consumption and associated greenhouse gas emissions, there are clear sustainability benefits of RTS as well.

INTRODUCTION

Real-time smoothness (RTS) is a quality control tool for assessing pavement smoothness during paving operations. The Second Strategic Highway Research Program (SHRP2) R06E project titled Real-Time Smoothness Measurements on Portland Cement Concrete Pavements During Construction helped to advance real-time smoothness measuring technologies through unbiased field evaluations and demonstrations and the development of a draft model specification and guidelines (Rasmussen et al. 2013). The study provided validation of the technology for quality control and paving process improvements and improved understanding about which construction artifacts affect smoothness while also identifying current commercially available systems. In response to this study, the Federal Highway Administration (FHWA), through the SHRP2 Solutions Implementation Assistance Program, funded additional follow-up work to continue development and implementation, with the goal to eventually achieve routine use of real-time smoothness measuring technologies by owner-agencies and paving contractors (Fick et al. 2020). A key aspect of the implementation effort has been an equipment loan program that allows owner-agencies and contractors the opportunity to evaluate RTS technology on active concrete paving projects using FHWA-owned RTS systems. The equipment loans were continued under the present cooperative agreement between FHWA and the National Concrete Pavement Technology Center (CP Tech Center). This report summarizes key findings from these implementation efforts through documentation of the current state of the practice and an explanation of the value proposition of RTS technology.

STATE OF THE PRACTICE

The current state of the practice with respect to RTS technology, utilization by contractors, and key lessons learned from demonstration projects under the equipment loan program is described below.

Real-Time Smoothness Systems

There are currently three known commercially available RTS systems for concrete paving: GOMACO Smoothness Indicator (GSI), Ames Engineering Real-Time Profiler (RTP), and Surface Systems & Instruments, Inc. (SSI) Onpaver Profiler (OPP). These systems all utilize slightly different hardware for collecting profile data, and each has its own user interface and data collection and analysis software, but all are able to provide accurate profile traces on fresh concrete surfaces behind slipform pavers. The key elements of an RTS system are the profiling sensors, distance measurement tools, and real-time display (user interface).

Profiling Sensors

Profiling sensors collect the actual pavement profile data by measuring the distance between the sensor and the pavement surface, similar to an inertial profiler. However, because these devices operate on a slow-moving slipform paver, it is not necessary to establish an inertial reference to account for vertical movement of the paver with an accelerometer.

The Ames RTP and SSI OPP utilize laser sensors for measuring the distance between the sensor and pavement surface. The Ames RTP utilizes three single-spot laser sensors and must be installed and leveled within 6 in. of the pavement surface. The SSI OPP utilizes a single line laser sensor offset at least 4 ft from the pavement surface and measures the pitch and roll of the paver frame through an inclinometer sensor. The GSI utilizes two acoustic sensors and a slope meter (Figure 1).

Figure 1. Various RTS sensors: Ames RTP (top), GSI (middle), SSI OPP (bottom)

All three systems can measure at least four profile traces simultaneously across the back of the paver. Currently, all systems measure a two-dimensional profile trace and report profile data every 1 to 3 in.

Distance Measurement Tools

All three systems utilize an encoder wheel mounted to the paver to record the distance traveled during profile data collection. The Ames RTP utilizes a bicycle wheel-style distance measurement instrument (DMI) that is typically mounted to the side of the paver between the front and rear tracks. The Ames RTP also features a Global Positioning System (GPS) receiver to continuously record GPS coordinates during profile data collection. The GSI and SSI OPP DMIs measure distance using the paver tracks. The SSI OPP utilizes an optical encoder while the GSI utilizes a small wheel mounted to the top of one of the fenders. The GSI can also utilize the onboard distance measurement built into the paver on newer GOMACO G+ pavers (Figure 2).

Figure 2. DMI options for Ames RTP (top) and GSI (bottom)

Real-Time Display

All three systems feature a display typically mounted to the side of the paver near other paver controls to provide real-time reporting of profiles and smoothness results.

All three systems utilize vendor-specific software that is capable of reporting international roughness index (IRI), mean roughness index (MRI), half-car roughness index (HRI), or profilograph index (PrI) smoothness values at user-selected intervals. All of the systems also report localized roughness based on user-specified settings, typically using a continuous roughness IRI report, profilograph bump template, or straightedge simulation, and are capable of documenting events manually entered by the user or automatically tracked by the system (e.g., paver stops). The SSI OPP and GSI systems also include controlled area network (CAN) bus messages that can send and receive information between the RTS electronics and the paver.

The Ames RTP utilizes a standalone rugged laptop, which can be disconnected at the end of the day and used for data analysis away from the jobsite. The SSI OPP utilizes a rugged tablet, which can also be disconnected and used for data analysis away from the jobsite. The GSI utilizes a tablet-style display to collect the data, which can then be downloaded to a flash drive and analyzed on a separate computer using the GSI software. The GSI can also be integrated into the paver control system on newer GOMACO G+ pavers so that other paver settings (e.g., vibrators, grade control, dowel bar insertion) can be monitored (Figure 3).

Figure 3. Various RTS displays: Ames RTP laptop (top), GSI tablet (middle), SSI OPP tablet (bottom)

All three systems output profile data in a format that can be imported into FHWA's ProVAL software (ProVAL 2024) for analysis.

Future Enhancements

RTS vendors are continually evaluating potential upgrades to their systems to improve installation and operation. These include upgrades to the equipment for portability and ruggedness and upgrades to the user interface to ensure that the systems are providing the information that contractors are most interested in using.

To date, no RTS vendor has indicated a move toward LiDAR-based sensors or three-dimensional profiling, and no RTS vendor has implemented a system for automated machine control of the paver based on feedback from the RTS system.

RTS Utilization

The use of RTS systems varies widely. Many contractors use the technology regularly, particularly on mainline paving projects with stricter smoothness requirements. Some contractors own the technology but use it selectively, depending on the project requirements and paving crew. It is more common to see it used in states with mature pavement smoothness programs and smoothness requirements, particularly states where IRI is used for acceptance. The use of RTS is not mandated by any agencies, and there are no known plans for agencies to adopt a requirement for its use.

While the exact number of RTS systems utilized on a regular basis is unknown, discussions with RTS vendors suggest that over 150 RTS systems are currently in use nationwide, with a number of contractors owning more than one system.

Over the course of RTS implementation, which began with FHWA's efforts under the SHRP2 Solutions Implementation Assistance Program and continued through additional FHWA implementation efforts, including the current cooperative agreement between FWHA and the CP Tech Center (CP Tech Center n.d.), 25 equipment loans have been completed in 18 states. While several states have hosted more than one demonstration, each demonstration was with a different contractor and provided the opportunity to evaluate the use of RTS for a wide variety of concrete pavement projects, such as the following:

- Various roadway types: urban and rural, Interstate, county roads, arterials, etc.
- Various pavement types: jointed plain concrete pavement (JPCP), continuously reinforced concrete pavement (CRCP), unbonded overlays
- Varying slab thicknesses: 5 to 17.5 in.
- Varying slab widths, joint spacings, longitudinal joint types (tied, dowelled, plain)
- Varying base types: granular (unstabilized and stabilized), asphalt, cement-treated, pervious cement-treated
- Daytime and nighttime paving in all climatic regions
- Varying mix designs and material types (aggregates, supplementary cementitious materials, etc.)
- Various slipform paver types (GOMACO, Guntert & Zimmerman, Wirtgen)

- Various concrete delivery and placement methods (dump trucks, ready mix trucks, belt placers, placer-spreaders, etc.)
- Dowel baskets and dowel bar inserters (DBI)
- Stringline and stringless paving

While not all contractors who participated in the equipment loan program have responded to inquiries regarding their use of RTS, at least 8 to 10 RTS systems have been purchased by contractors who participated in the equipment loan program.

Contractor Feedback

Feedback received from contractors participating in the equipment loan program regarding the use of RTS included the following:

- "It is helpful to see 'real-time' smoothness so the contractor can try and make adjustments in the field during paving operation to try and maximize the ride of the pavement. This could be adjustments to the paver, the concrete mix, etc."
- "We did purchase a GSI, but taking care of the equipment with all of our moves and paver changes combined with 'picking a job' and placing it on a paver has been the biggest challenge for us. None of us has enough qualified help, so finding and keeping people that will take ownership is a challenge at best."
- "We did not purchase the unit yet, but I do see us getting one in the future. It was very valuable information that it gave me, and I was able to make some changes to our procedures that gave immediate benefits in ride scores."
- "We currently have one [Ames] RTP and two GSI units, used occasionally, depending on the crew."
- "We think it's a great learning tool for the crew to develop better practices and troubleshoot paving issues."
- "We already had an older system, but the demo encouraged us to upgrade to a newer system."
- "We already had a newer GSI, but the demo encouraged us to use it regularly and helped us to understand how to use the system better."
- "We had an older GSI at one time, but still don't use it regularly."
- "We appreciated the RTS demo, but our jobs are highly staged reconstruction projects."
- "We feel that it doesn't give us a true picture because of the work done behind the paving (e.g., texturing), which seems to impact the profile."

RTS for Improving Smoothness

A general guide for implementing RTS based on lessons learned from the equipment loans completed under the original SHRP2 Solutions Implementation Assistance Program is summarized in Fick et al. (2020). However, based on the equipment loans completed to date, three primary motivations for using RTS as a quality control tool are summarized below.

1. RTS Provides a General Idea of Smoothness During Paving

While RTS and hardened concrete profiles are never identical due to the finishing, texturing, and joint sawing processes that occur between measurement of the RTS profile and measurement of the hardened concrete profile, the profiles still show very similar trends. The resultant IRI values for the RTS and hardened concrete profiles also show similar trends, even though the IRI values themselves may be significantly different. In general, the RTS IRI values are higher than those of the hardened pavement, but this is not always the case. While there is no single correlation between RTS and hardened concrete smoothness numbers that applies to all projects, contractors who utilize RTS regularly during mainline production paving will still obtain a general idea of what the RTS IRI values will correspond to in terms of hardened concrete IRI values.

Table 1 shows examples from two projects whose RTS profiles exhibit very different levels of roughness but relatively similar levels of roughness relative to the corresponding hardened concrete profile data. In general, the lower the RTS IRI values, the smaller the difference between the hardened concrete and RTS IRI values. In general, the lower the RTS IRI values, the lower the variation (as indicated by the standard deviation of the IRI values) of both the RTS IRI values and the difference between RTS and hardened concrete IRI values.

Table 1. Examples of differences between RTS and hardened concrete IRI values

IRI Measurement	Project A	Project B
Number of 0.1 mi Segments	12	15
RTS IRI (Avg.)	105.8	66.3
RTS IRI (Std. Dev.)	16.1	10.8
Hardened IRI (Avg.)	64.1	55.0
Hardened IRI (Std. Dev.)	6.6	7.4
Difference in IRI, RTS – Hardened (Avg.)	41.7	11.2
Difference in IRI, RTS – Hardened (Std. Dev.)	14.6	6.2

While an obvious feature or anomaly (e.g., transition onto a bridge deck or adjacent surface, drainage inlet, grade control interference, long paver stop) can be expected to lead to an area of localized roughness, RTS allows the contractor to assess the severity of the feature's impact on roughness during paving. Further, by comparing RTS profile data to hardened concrete profile data, the contractor is able to assess the improvement in smoothness achieved by the finishing process behind the paver. Figure 4 shows an example where the right side of the paver passed over a drainage structure, leading to an area of localized roughness. The RTS and hardened concrete IRI values show the severity of the area of localized roughness and the improvement achieved through the finishing process.

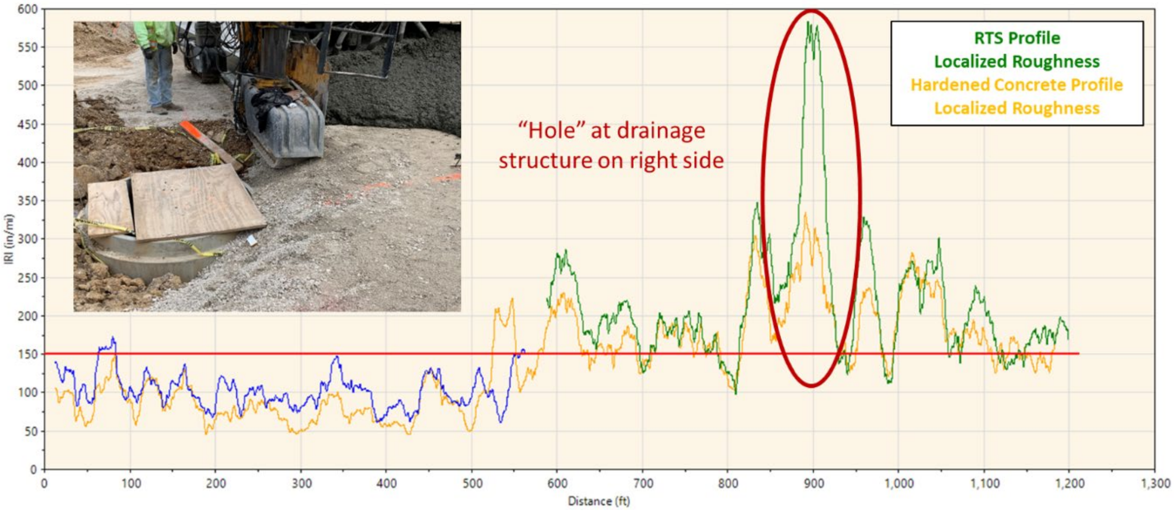


Figure 4. Example of how RTS data can be used to assess the severity of areas of localized roughness and the effectiveness of the associated corrective action

The key idea is that when using RTS during paving, there should not be any "surprises" in terms of overall smoothness or areas of localized roughness when the hardened concrete profile data are collected. It is critical, however, for the contractor to collect hardened concrete profile data and perform daily comparisons to the RTS profile data.

2. RTS Allows the Contractor to Assess the Impact of Changes to Paving Processes on Smoothness

Changes to paving processes are typically made based on how the concrete is moving through or responding to the paver and the appearance of the slab behind the paver. Adjustments are typically made when the contractor has difficulty maintaining a consistent and uniform head of concrete in the grout box; when the surface behind the paver is tearing, open, or honeycombed; or when there is edge slump. Paving process changes include the following:

- **Changes to the concrete mix**. Typically in response to how well the mix is moving through the paver and the appearance of the slab behind the paver. Changes to the mix may also be made in response to deficient or excessive air content or slump.
- **Changes to paver operation**. Typically includes adding or removing draft/lead/pitch to the pan, adjusting vibrator frequency and/or vibrator height, adjusting paver speed, adjusting sensitivities of grade control, and adjusting sensitivities of hydraulic response, among others. For pavers utilizing a DBI, changes to the operation of the DBI may also be necessary depending on the appearance of the surface behind the DBI.

Figure 5 shows an example from an equipment loan project where the contractor made a conscious effort to maintain a consistent and smaller head of material in front of the paver, which resulted in noticeably lower IRI values.

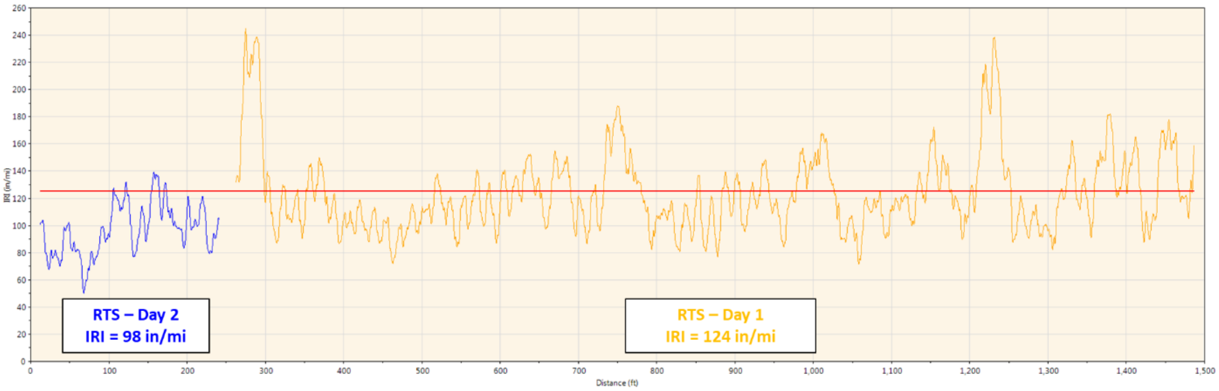


Figure 5. Example of change in RTS IRI values after adjustment of the concrete head in front of the paver

Table 2 shows another example from an equipment loan project where the contractor was able to diagnose an issue with the auto-float behind the paver by evaluating the RTS IRI values with and without the auto-float in operation. Note that when the auto-float was used, the hardened concrete IRI values were higher than the RTS IRI values, indicating that something was adding roughness to the surface behind the paver and RTS sensors. After discontinuing the use of the auto-float, the RTS and hardened profile IRI values were much lower and very similar to each other.

Table 2. Example of change in RTS and hardened concrete IRI values after adjustment of the finishing process

Paving Day	RTS IRI*	Hardened IRI*	Difference
Day 1 (with auto-float)	71 in./mi	92 in./mi	(+) 11 in./mi
Day 2 (no auto-float)	53 in./mi	48 in./mi	(-) 5 in./mi

*Average of two profile traces (shoulder and travel lane)

Figure 6 shows an example of a noticeable change in the IRI values of the RTS profile and the corresponding hardened profile after an adjustment was made to the hydraulic response sensitivity.

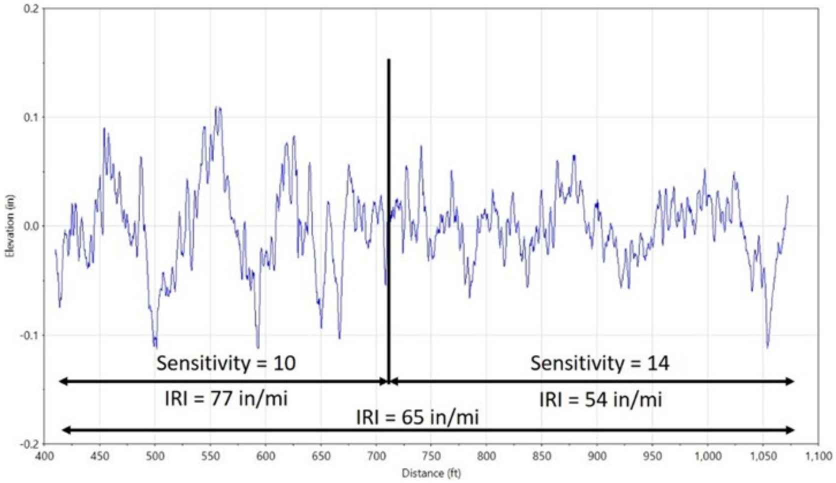


Figure 6. Example of change in IRI values after adjustment of the hydraulic response sensitivity

Figure 7 shows an example from an RTS demonstration where the RTS system plotted paver speed and RTS IRI values for the purpose of assessing the impact of paver speed on smoothness. While there is not a clear correlation between paver speed itself and smoothness, there does appear to be a correlation between paver speed consistency and smoothness, with a consistent paver speed (top) showing lower and less variable IRI values than a variable paver speed (bottom).

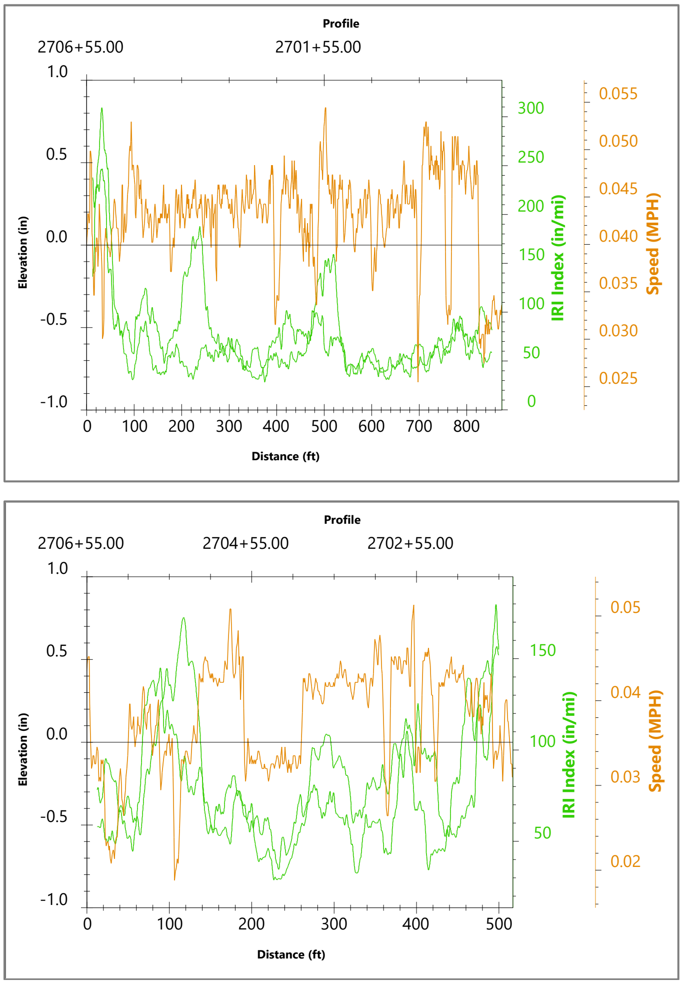


Figure 7. Example of an RTS system report comparing paver speed and roughness, with an example of consistent speed (top) and variable speed (bottom)

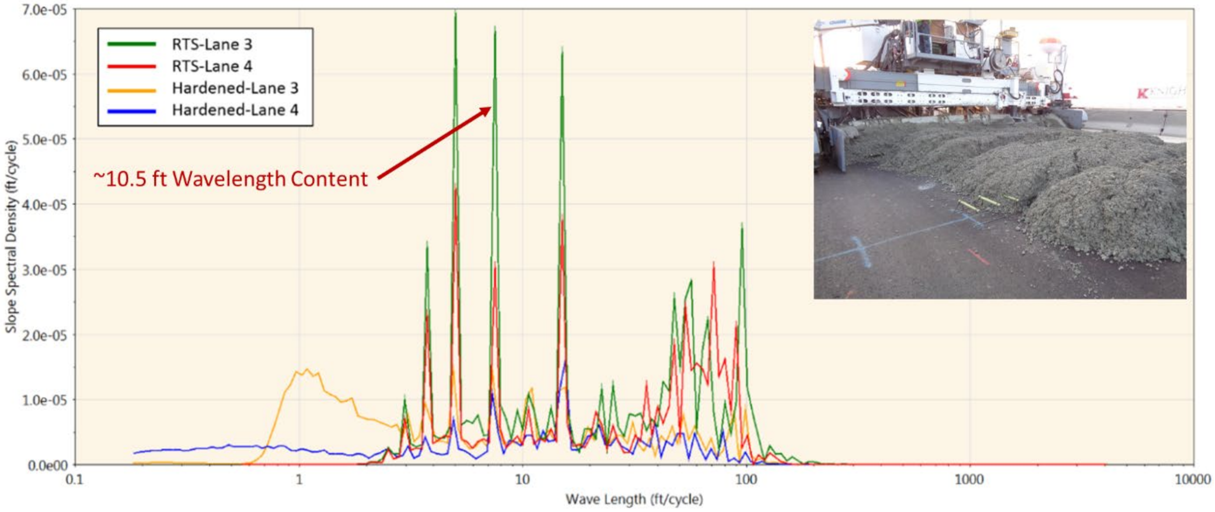
Each of these examples demonstrates how RTS systems can help contractors assess the impact of changes in paving processes on pavement smoothness in real time during paving.

3. RTS Helps the Contractor Identify and Mitigate Systematic Paving Factors that Affect Smoothness

As noted by Fick et al. (2020), because paving is very repetitive by nature, with the same processes repeated throughout the day’s operation, certain processes or features of pavement itself can leave “patterns” in the pavement profile that can affect smoothness. Joint spacing is a very basic example of a feature that creates a repeating pattern at regular intervals (e.g., every 15 to 20 ft corresponding to joint spacing) that can be reflected in the pavement profile, particularly when dowel baskets are used. However, other processes like concrete placement or load spacing in front of the paver, stringline pin spacing, and dowel bar and/or tie bar insertion can also leave patterns in the pavement surface that can be diagnosed through an analysis of RTS profile data.

One of the key tools for identifying these systematic paving factors that affect smoothness is a power spectral density (PSD) analysis. FHWA's ProVAL software (ProVAL 2024) contains a PSD analysis module to help identify these factors.

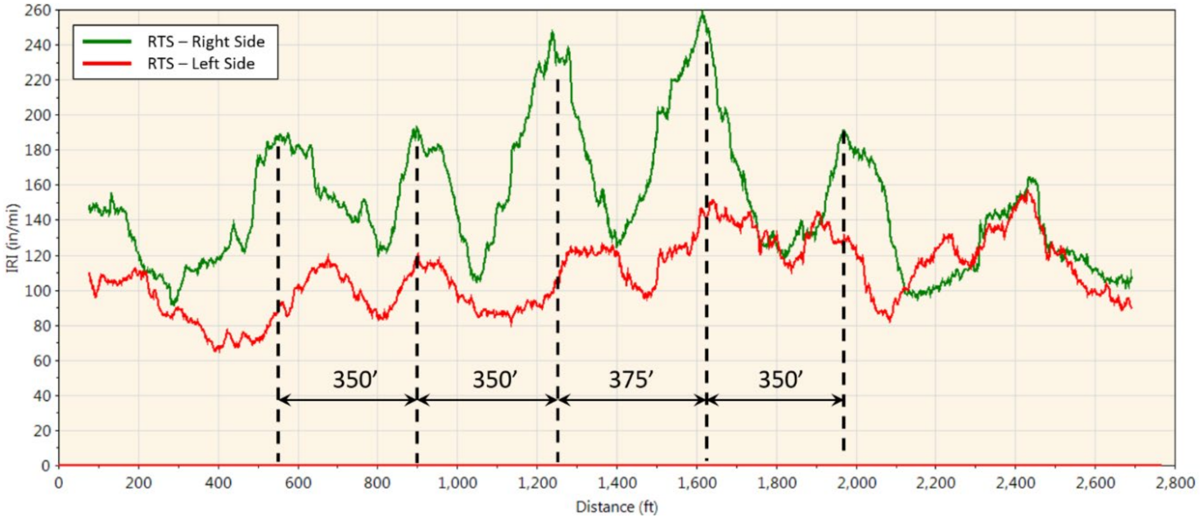
Figure 8 shows an example from an equipment loan project where a PSD analysis of the RTS data revealed a repeating feature at approximately 10.5 to 11 ft. (Note that the other peaks in the PSD plot are related to the joints/dowel baskets.) The feature also appeared in the hardened concrete profile data, although not as prominently. After reviewing various aspects of the paving operation, it was determined that the repeating feature corresponded to the spacing of the concrete loads. Even though each load was placed in front of the paver using a placer, there was enough load-to-load variation in the concrete mixture to leave a repeating pattern in the slab.



After Fick et al. 2020

Figure 8. Example of a concrete load spacing feature in RTS and hardened concrete profile data

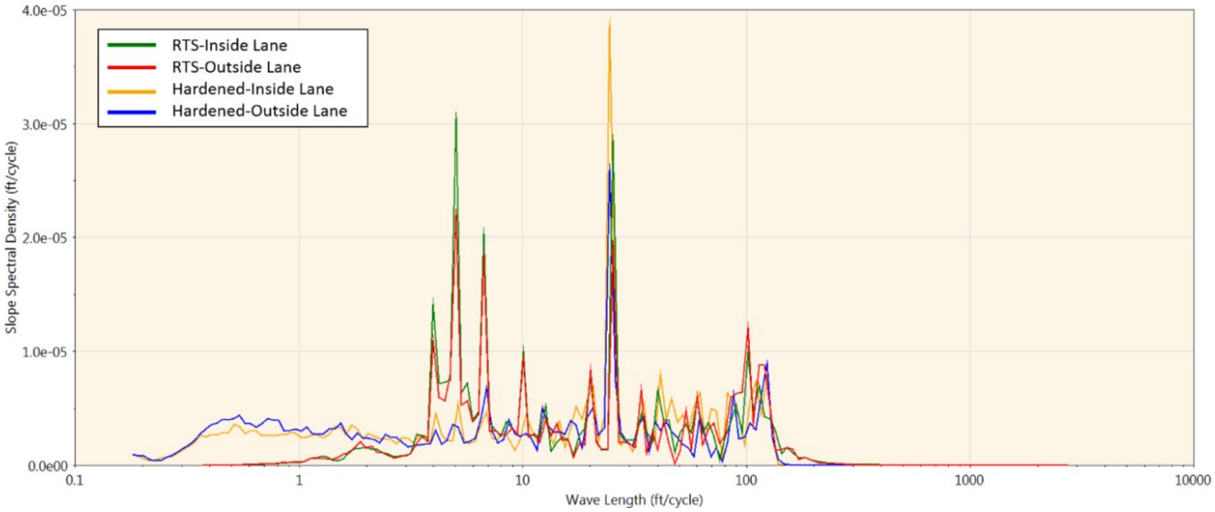
Figure 9 shows another example where the RTS data revealed a repeating pattern of increasing and decreasing roughness approximately every 350 to 375 ft. After reviewing various aspects of the paving operation, it was determined that this spacing corresponded to the spacing of the total stations for the stringless grade control system. The contractor shortened the spacing of the total stations for subsequent nights of paving based on this finding from the RTS system.



Fick et al. 2020

Figure 9. Example of the effects of stringless grade control in RTS profile data

Figure 10 shows an example where the stringline support pin spacing appeared as a repeating pattern in the RTS data. Although the IRI values were still very good, the RTS data provided feedback for possible adjustments to the stringline that could improve smoothness even more.



Fick et al. 2020

Figure 10. Example of stringline pin support spacing in RTS and hardened concrete profile data

VALUE PROPOSITION

RTS is a quality control tool for slipform pavement construction. As such, the primary benefit of RTS will be realized by contractors. There are, however, benefits to owner-agencies and the traveling public, as discussed below.

Value to Contractors

While installing RTS on a paver does not guarantee a smoother pavement, it is one more tool that can help contractors achieve smoothness requirements if they are willing to invest in the equipment and the time and effort to learn how to best utilize the technology.

Cost

As a contractor quality control tool, the cost of ownership and operation of RTS falls on the contractor. With respect to the cost of ownership, RTS systems currently cost on the order of $60,000 to $70,000 for a dual-sensor system (two wheel path traces) for a single paver. There will be some additional marginal cost to install the equipment on the paver and to train contractor personnel on equipment operation. Note, however, that operation is not substantially different from the collection of profile data on the finished pavement surface, which many contractors do themselves already.

While these systems are all very robust, routine cleaning and maintenance of system components is always beneficial. The cost of these activities should be minimal and consistent with routine maintenance of all paving equipment. Under heavy use, annual calibration of the profile sensors and DMI wheel encoders by the RTS manufacturer is good practice, but not always required, and the cost should be minimal (under $5,000).

The cost of operation is also minimal. Once the RTS system is installed on a paver, the daily setup prior to paving and breakdown after paving should take less than 15 minutes. Startup prior to paving requires an operator to verify system operation, enter project information, and start data collection. This is often performed by the paving foreman or survey crew personnel and does not require a dedicated additional person on the paving crew. Regular monitoring of the data during paving is typically handled by the foreman or superintendent and does not require constant attention or an additional person on the crew.

Benefits

Although there are likely more, three key motivations for using RTS to help improve as-constructed smoothness are summarized above. In addition to the benefits resulting from these uses of the technology, the financial benefits of improved smoothness are realized through increased incentives (bonus payments), decreased disincentives (reductions in payment), and a reduced need for corrective action (grinding or removal and replacement).

For reference, consider the range of IRI values for construction acceptance and the associated pay adjustments for concrete pavements reported by Merritt et al. (2015) in Table 3 (noting that these values have likely changed somewhat since 2015 as more states have adopted IRI specifications). Table 4 further shows the range of pay adjustment values from states with IRI-based specifications for concrete pavement. The vast majority (80%) of state highway agencies with IRI-based smoothness specifications for concrete pavement include incentive and disincentive pay adjustments for smoothness (Merritt et al. 2015).

Table 3. Summary of average IRI thresholds from concrete pavement specifications in the United States

	Incentive Upper Limit	Full Pay Lower Limit	Full Pay Upper Limit	Disincentive Lower Limit	Disincentive Upper Limit	Threshold for Correction
Min	39.9	40.0	54.0	54.1	67.5	60
Max	70	71	93.0	93.1	140.0	150
Avg.	56.2	56.5	71.7	72.5	95.3	96.9
Median*	55	55.1	70	70.1	95	95

*Median values were not provided in the original report but were derived from the same data set.
After Merritt et al. 2015

Table 4. Summary of average IRI pay adjustments from concrete pavement specifications in the United States

Incentive/Disincentive Basis		Max Incentive	Max Disincentive
$ per 0.1 mi lot *(13 states)*	Min	$200	-$250
	Max	$1,600	-$1,750
	Avg.	$825	-$831
	Median*	$813	-$750
Pct. contract price *(7 states)*	Min	102%	90%
	Max	108%	50%
	Avg.	105%	75%
	Median*	105%	80%

*Median values were not provided in the original report but were derived from the same data set.
After Merritt et al. 2015

Note that even a small (e.g., 10% to 15%) improvement in smoothness can mean the difference between receiving full pay versus a reduced payment (disincentive) or the difference between a significant incentive payment and simply full pay. From the example in Figure 6 above, a change in hydraulic response sensitivity in response to higher IRI values from the RTS system led to a 30% improvement in smoothness from one section to the next, or an overall improvement of approximately 17% when the segments are combined.

The potential financial benefits for exceptional smoothness can be substantial. Considering just the median values from Table 4, there is potential for over $8,100 of incentive pay per lane mile for paving under 0.1 mi lot acceptance and over $31,600 per lane mile for paving under a percent contract price specification (assuming a unit bid price of $90/yd^3).

Conversely, the financial disincentives or the cost of correction for unsatisfactory smoothness can also be substantial. Considering the median values from Table 4, there is potential for over \$7,500 of reduced payment per lane mile for paving under 0.1 mi lot acceptance and over \$126,000 of reduced payment per lane mile for paving under a percent contract price specification (assuming a unit bid price of \$90/yd^3).

With respect to corrective action, the cost of diamond grinding typically ranges from \$5/yd^3 to \$7/yd^3, including mobilization, depending on aggregate type, or \$900/hour to \$1,200/hour plus mobilization for spot grinding. Some agencies require corrective action to an entire segment (e.g., 0.1 mi) if the segment is found to be deficient. This translates to approximately \$3,500 to \$4,900 per 0.1 lane mile of pavement.

Value to Owner-Agencies

The value of RTS to owner-agencies is primarily related to the construction of a superior final product by the contractor. While there are a number of project-related and construction-related factors that affect the level of smoothness that can be achieved, smoothness is typically a key indicator of construction quality. This is not to say that pavements with higher levels of roughness are poor-quality pavements, but a high level of smoothness relative to what is achievable is an indicator of attention to quality during construction.

A superior final product will ultimately save owner-agencies money over the life of the pavement. As documented by the authors in a previous report, there is evidence that pavements built smoother initially will stay smoother longer and that smoother pavements will last longer, requiring less maintenance and extending pavement repair and rehabilitation cycles (Fick et al. 2020). This results in cost savings to the agency and ultimately the traveling public.

Research for the Indiana Department of Transportation evaluated pay factors for IRI-based concrete pavement smoothness specifications based on expected pavement performance as a function of initial (as-constructed) IRI and truck traffic exposure. Models were developed for the estimation of future IRI based on initial IRI using historical pavement performance data that considered the ratio of observed to as-designed pavement life. Life-cycle cost analysis was further used to capture the costs of pavement maintenance and rehabilitation over the life of the pavement as a function of initial IRI, such that pay adjustments would account for these costs (Harris 2013).

The resultant pay factors provide incentive pay of 8% for an IRI of less than 35 in./mi, gradually decreasing to full pay for an IRI between 60 and 70 in./mi. Graduated disincentive pay adjustments begin at an IRI of 71 in./mi to a maximum of 95% pay reduction at 90 in./mi, and corrective action is required above 90 in./mi (INDOT 2024).

A less tangible, more anecdotal benefit for agencies is increased market competition to produce a quality final product. Contractors with rigorous quality control practices that utilize tools like RTS will generally be able to maximize the smoothness incentive payment, allowing them to effectively lower their initial bid price and win more projects. The agency, in turn, benefits from a superior product built by a conscientious contractor.

Sustainability and Value to the Traveling Public

Similar to the value for owner-agencies, the value of RTS to the traveling public primarily comes from a superior final product. RTS is a tool that can help contractors achieve higher levels of smoothness, which is important to the traveling public. This was recognized as far back as the original American Association of State Highway Officials (AASHO) Road Test, which found that users judge the quality of a roadway primarily by its ride quality (Carey and Irick 1960). A more recent study by the North Carolina Department of Transportation found that users generally rate a pavement with an IRI less than 103 in./mi as "acceptable" and pavements over 151 in./mi as "unacceptable," and therefore a target IRI for initial construction of 60 to 70 in./mi is recommended to help ensure that an acceptable ride quality for the traveling public is maintained over the life of the pavement (Chen et al. 2014). User satisfaction is one reason agencies have continued to focus on pavement smoothness, continually refining specifications to maximize smoothness as much as practical. There is also evidence that smoother pavement results in less wear and tear on vehicles (Sime and Ashmore 2000), which also benefits the traveling public.

User-related sustainability benefits of smoother pavements are realized through reduced fuel consumption and associated reductions in greenhouse gas emissions. The impact of smoothness on fuel consumption can be quantified using pavement-vehicle interaction models that have been developed in recent years to estimate excess fuel consumption caused by rolling resistance from pavement deflection (related to the stiffness of a pavement structure) and pavement surface characteristics such as smoothness and texture. For example, models developed through research at the MIT Concrete Sustainability Hub can quantify fuel consumption based on pavement smoothness (Louhghalam et al. 2017). Additionally, the International Grooving and Grinding Association maintains a website with a carbon calculator where these costs can be quantified (IGGA n.d.).

To illustrate the potential costs of fuel consumption related to roughness, consider the smoothness values from one of the recent RTS demonstration projects, shown in Figure 6 above, where IRI decreased from 77 in./mi to 54 in./mi after the hydraulic response sensitivity was adjusted based on results from the RTS system. Table 5 summarizes the traffic characteristics of the rural Interstate roadway where this project was constructed, which has a relatively low traffic volume but a very high percentage of trucks. The table also summarizes the inputs used for the carbon savings calculator and the results from the analysis. In addition to the fuel and carbon savings from the improvement in smoothness, the cost of diamond grinding is shown if the smoothness improvement were to have come from grinding versus adjustments to the paving process. (Note that diamond grinding would likely have reduced roughness significantly more, resulting in additional savings in fuel and carbon.)

From this example, the annual savings in fuel and carbon emissions from an improvement in the paving process to reduce IRI is significant and would be substantially higher on roadways with higher traffic volumes. In addition, the cost of diamond grinding per lane mile is approximately two-thirds of the cost of an RTS system. While this is a simplistic example with many assumptions related to the improvement in smoothness from RTS and diamond grinding, it helps to demonstrate the potential sustainability benefits of improving as-constructed smoothness.

Table 5. Example of fuel and carbon savings from improved smoothness

Roadway Traffic Characteristics	AADT	2,790
	Truck Traffic	43%
	Design Speed	70 mph
Average Fuel Cost*	Regular	\$3.35/gal
	Diesel	\$3.71/gal
Smoothness Results	IRI before Adjustment	77 in./mi
	IRI after Adjustment	54 in./mi
Fuel and Carbon Savings/Contribution	Annual Fuel Savings (per mile)	\$2,454 200 gal (regular) 477 gal (diesel)
	Annual Carbon Savings (per mile)	6.7 metric tons
	Diamond Grinding Cost (\$6/yd^3)	\$42,240
	Carbon Associated with Fuel Consumed during Grinding (per mile)	8.6 metric tons

* National average gas prices for August 2024 as reported by AAA n.d.

CONCLUSIONS AND RECOMMENDATIONS

Since 2015, 25 demonstrations of RTS have been completed through equipment loans to 25 different contractors in 18 states under various SHRP2 and FHWA implementation efforts. These projects have included a wide variety of concrete pavement types and design features as well as a variety of paver types and paving train setups. The feedback from contractors participating in the demonstrations has been positive, even if the contractor did not utilize the RTS data to make adjustments to paving operations. Contractors who did make adjustments to paving processes as a result of feedback from RTS data generally saw improvements in smoothness numbers.

The cost of ownership of an RTS system is minimal in comparison to the size of most concrete paving projects. Additionally, with the majority of concrete pavement smoothness specifications nationwide including incentive payment for high levels of smoothness, there is the potential to offset the initial cost of an RTS system with only one paving project. Considering the cost of corrective action such as diamond grinding or removal and replacement, it becomes even easier to justify the cost of an RTS system, even if it provides only a minimal amount of improvement in smoothness.

While the financial benefits of using RTS will primarily be realized by contractors, the potential for improving as-constructed smoothness also benefits owner-agencies and the traveling public. With pavement roughness being a primary contributor to excess fuel consumption and associated greenhouse gas emissions, there are clear sustainability benefits to RTS as well.

Smoothness will continue to be a key element of concrete pavement smoothness specifications, particularly as pavement profiling technology continues to improve and the factors that affect pavement smoothness and the impact of smoothness on pavement performance are better understood. Owner-agencies will likely continue to incentivize exceptional smoothness, and as concrete materials and paving equipment continue to evolve and improve, higher levels of smoothness become more achievable. RTS is one more quality control tool to help contractors achieve these requirements to maximize smoothness and potential incentives.

RTS is a valuable quality control tool for helping contractors improve as-constructed smoothness. It is recommended that concrete paving contractors consider the use of this technology to better understand the impact of the many aspects of a paving operation on smoothness. Guidelines for implementing RTS on concrete paving projects have been laid out by Fick et al. (2020), and RTS vendors provide hands-on support for installation and the training of contractor personnel to implement this valuable tool.

REFERENCES

AAA. n.d. National Average Gas Prices. American Automobile Association. https://gasprices.aaa.com/.

Carey Jr., W. N., and P. E. Irick. 1960. *The Pavement Serviceability-Performance Concept*. HRB Bulletin 250. Highway Research Board, Washington, DC. http://onlinepubs.trb.org/Onlinepubs/hrbbulletin/250/250-003.pdf.

Chen, D., J. Hildreth, V. W. Ogunro, X. Fang, and C. Laville. 2014. *Development of IRI Limits and Targets for Network Management and Construction Approval Purposes*. Engineering Technology and Construction Management, University of North Carolina, Charlotte, NC.

CP Tech Center. n.d. Real-Time Smoothness (RTS). National Concrete Pavement Technology Center. https://cptechcenter.org/real-time-smoothness/.

Fick, G., D. Merritt, P. Taylor, T. Hanke, H. Torres, and R. Rasmussen. 2020. *Implementation Support for Second Strategic Highway Research Program (SHRP2) Renewal R06E Real-Time Smoothness Measurements on Portland Cement Concrete Pavements during Construction*. National Concrete Pavement Technology Center, Iowa State University, Ames, IA.

Harris, D. 2013. *Development of Methods and Specifications for the Use of Inertial Profilers and the International Roughness Index for Newly Constructed Pavement*. Joint Transportation Research Program, Purdue University, West Lafayette, IN.

IGGA. n.d. Fuel/Carbon Savings Calculator. International Grooving and Grinding Association. https://calculators.igga.net/.

INDOT. 2024. Section 501.25. *2024 Standard Specifications*. Indiana Department of Transportation, Indianapolis, IN.

Louhghalam, A., M. Akbarian, and F. Ulm. 2017. Carbon management of infrastructure performance: Integrated big data analytics and pavement-vehicle-interactions. *Journal of Cleaner Production*, Vol. 142, Part 2, pp. 956–964.

Merritt, D. K., G. K. Chang, and J. L. Rutledge. 2015. *Best Practices for Achieving and Measuring Pavement Smoothness, A Synthesis of State-of-Practice.* Southeast Transportation Consortium and Louisiana Transportation Research Center, Baton Rouge, LA.

ProVAL. 2024. ProVAL. The Transtec Group, Inc. https://www.roadprofile.com/.

Rasmussen, R. O., H. N. Torres, R. C. Sohaney, S. M. Karamihas, and G. J. Fick. 2013. *SHRP2 Report S2-R06E-RR-1: Real-Time Smoothness Measurements on Portland Cement Concrete Pavements During Construction*. Second Strategic Highway Research Program, Washington, DC.

Sime, M., and S.C. Ashmore. 2000. *WesTrack Track Roughness, Fuel Consumption, and Maintenance Costs.* FHWA-RD-00-052. Federal Highway Administration, Turner-Fairbank Highway Research Center, McLean, VA.

Swanlund, M. 2000. Enhancing pavement smoothness. *Public Roads*. Volume 64, No. 2.

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