Guidelines for Ride Quality Acceptance of Pavements

A ride quality specification provides a way to reward or penalize contractor performance, as well as a way to predict future roadway performance.

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Initial ride quality is an important characteristic in determining the acceptance of a newly paved road. The user can easily recognize such imperfections as bumps and dips and may experience an uncomfortable ride. Smooth riding pavements provide a safe and comfortable ride for roadway users.

Some experts in highway construction contend that smoother pavements not only benefit users but also perform better than excessively rough pavements.[1] It is, therefore, important to understand and to measure road roughness in a consistent way. Road roughness can be conceptualized as the deviation of a pavement surface from a true planar surface, with characteristic dimensions that affect ride quality.[1] Ride quality can be described as the interaction of a vehicle and the road surface profile or roughness. When a pavement lacks roughness, it is referred to as a smooth pavement.

The majority of state highway administrations (SHAs) in New England measure roughness in units specified by the International Roughness Index (IRI). The World Bank in Brazil developed this standard unit of measurement in 1982 under the International Road Roughness Experiment (see Figure 1).[2] It is defined as the ratio of accumulated suspension motion (reference average rectified slope) to distance traveled of a standard quarter-car simulation (one front wheel) at a speed of 55 miles per hour. It can also be reported as a half-car simulation (two front wheels).[2]

A contractor is typically responsible for paving a smooth riding road that will be acceptable to the user and the responsible highway agency. Many highway agencies are currently establishing ride quality specifications that require the contractor to meet a certain level of smoothness (*i.e.*, an IRI value) after initial construction. These agencies may also incorporate incentives and penalties into their payment formulas to encourage contractors to meet their requirements. This payment formula, in part, dictates how much the contractor is paid for the paving job.

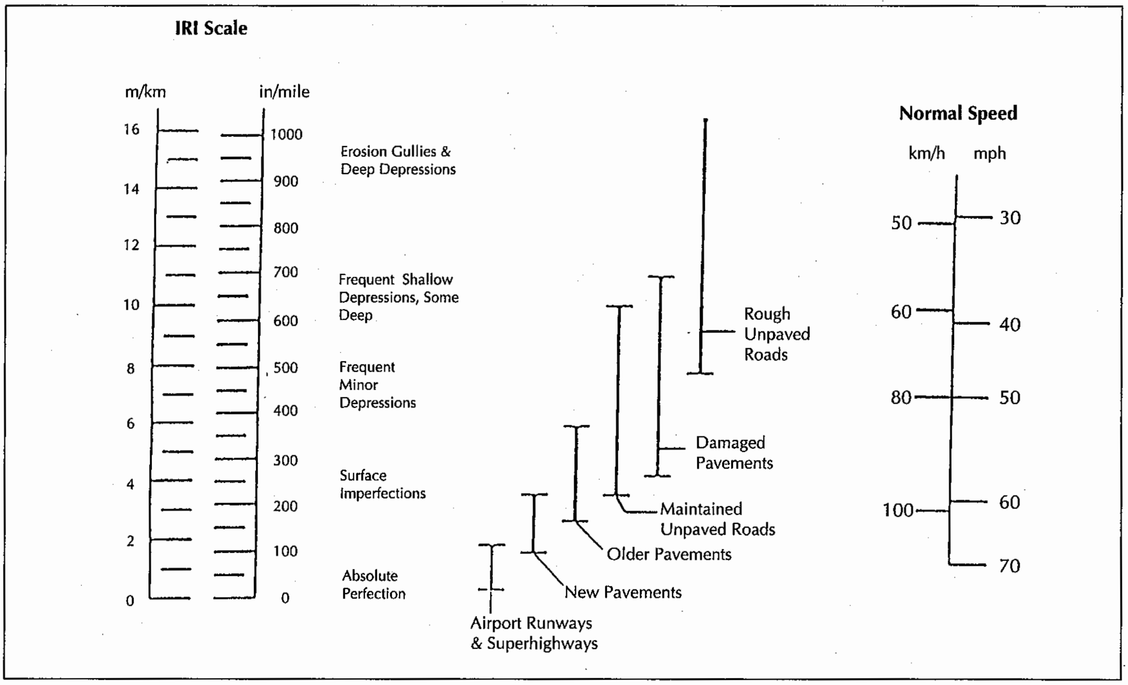

FIGURE 1. The IRI scale.

Contractors in New England, at present, use a straightedge as their main device for testing pavement smoothness. The straightedge, which can be used while paving is still in progress, is the most economical measuring device for the contractor. The straightedge is placed on the surface of the pavement, and the distance between the bottom of the device and the surface of the pavement is measured. The pavement is deemed acceptable if the measured distance is less than a specified tolerance limit.

Most SHAs in the United States use more sophisticated equipment to measure smoothness. Some use laser or acoustic sensors to measure the profile of a newly paved road. Others use response-type equipment that records vertical displacement. The profilograph, a response-type system, is the most widely used device in the United States for assessing the initial ride quality of pavement.[3] The different classes and the type(s) of ride quality measuring device(s) that are typically used to measure initial smoothness are shown in Table 1. (For more information related to these measuring devices refer to Black.[4])

Approximately 18 SHAs in the United States are implementing initial smoothness specifications that include incentives and penalties in their payment schemes.[3] These specifications, which have been designed and implemented with the notion that lower initial pavement roughness will result in a better-performing pavement, provide clear guidelines for contractors to use in producing a smooth pavement.

Because state highway officials in New England are in the process of designing and implementing initial ride quality specifications, they are very interested in addressing a number of issues and questions relating to ride quality acceptance.[5] Such questions include:

- What is a smooth riding pavement and how can smoothness be measured quantitatively?
- How can different levels of smoothness (or ride quality) be distinguished?
- What is an appropriate level of ride quality for various functional classes of highways?
- Do acceptable (or tolerable) levels vary by pavement type or method of construction?
- Does an initial ride quality specification enhance the overall quality and life of a pavement?

- Does the use of such specifications lead to increased construction costs or lengthened schedules?
- What are advantages, disadvantages and limitations of various pieces of equipment and measurement methods, and are these devices and methods equally appropriate for rigid and flexible pavements?
- How might payments to contractors be associated with smoothness specifications?

The consensus among SHA officials in New England is that obtaining answers to these questions will provide a basis for the consideration and development of appropriate ride quality acceptance specifications and suitable measurement procedures and methods for their states.[5]

Research was conducted to develop guidelines to assist New England SHAs in the formulation of appropriate specifications and implementation procedures for ride quality on new pavements. Implicit in conducting this research is the understanding that no one specification and procedure will meet all the needs of all six SHAs. Specifications and procedures are likely to vary depending on highway functional classification, type of construction (*e.g.*, new construction, reconstruction or rehabilitation), paving materials (*e.g.*, bituminous asphalt concrete [BAC] or Portland cement concrete [PCC]), availability of measurement equipment and other factors.[5] A special effort has been made to offer guidelines that are suitable for use in New England and sensitive to the region's environmental and geographic conditions; the administrative, construction and paving practices of each state; the availability of staff, equipment and other resources in each state; legal issues and their implications; and other factors.

TABLE 1.
Classes of Initial Ride Quality Measurement Methods

Class I. Manual Methods
Survey rod & level
Straightedge
Face technologies dipstick

Class II. Dynamic, Direct Profile Methods
Profilometers
Automatic road analyzer (ARAN)

Class III. Response-Type Indirect Measurements
Road meters

Selected Ride Quality Studies

Pennsylvania Transportation Institute Study. In a 1989 Pennsylvania Transportation Institute study, Kulakowski and Wambold reviewed methods and equipment used by 36 SHAs in the United States for measuring the roughness of new pavements.[6] The study revealed that many types of equipment for measuring roughness were being used to evaluate new pavements. The profilograph (essentially a 25-foot straightedge equipped with a transducer for measuring vertical displacement as the profilograph moves over the road surface) was found to be the most popular device (used by 21 SHAs). The road meter and the profilograph were the next most popular devices, each used in three states. A profilometer device was used in two states and the roughmeter was used in one state.

The Pennsylvania study also surveyed the blanking band measurements used by each SHA. The blanking band is used to identify the bumps and dips in the profile that must be corrected in a new wearing surface. Figure 2 shows a blanking band of 0.1 inches. Kulakowski and Wambold discovered that the most commonly used blanking band — used in 16 states — was 0.2 inches.[6] Any bumps or dips measured vertically that fall outside this 0.2-inch band, usually referred to as *outliers*, have to be corrected. The straightedge, used by 92 percent of the states surveyed, is employed in the field to identify these bumps and dips.

The study further determined that overall rideability and outlier measurements are the specifications used by most SHAs. Rideability is viewed as an aggregate, representative measure of pavement smoothness as perceived by the road user over the entire roadway section, while outlier measurements are used to identify and correct vertical displacements (*i.e.*, bumps and dips) at specific locations along the section.

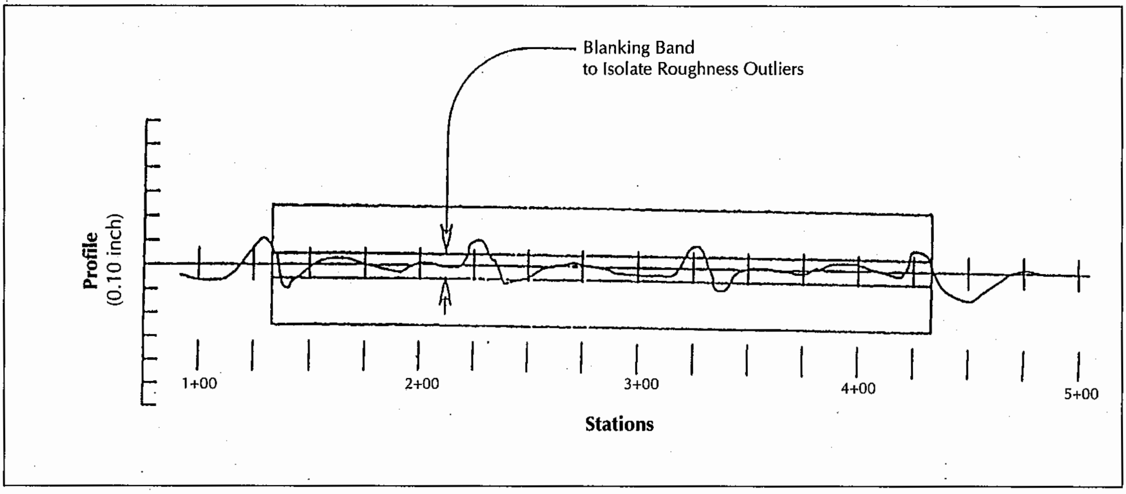

FIGURE 2. A blanking band as applied to a profilograph trace.

Arizona Department of Transportation Study. A study sponsored by the Arizona Department of Transportation (ADOT) covered techniques and devices used to measure pavement smoothness.[7] Four devices, including a surface dynamics profilometer, a roughness surveyor, a ride meter and a profilograph were evaluated and ranked according to their performance. These devices were tested for quality of roughness data, instrumentation precision and reliability, operating restrictions, set-up and operating complexities, equipment durability, automated data collection and processing, equipment versatility and cost. A comparison of all the devices is presented in Table 2.

Overall, the study found the profilometer as the best device for measuring roughness. The ride meter was second only because it needed regular calibration. The profilograph was labor-intensive and slow, but was considered an acceptable device for measurement. The roughness surveyor required improvements in durability and reliability.

University of Wyoming Study. In 1995, a study was conducted at the University of Wyoming that determined that straightedges and profilographs were currently the most widely used devices for assessing the smoothness acceptance of new pavements.[8] The straightedge was used by 16 SHAs and the profilograph-type device by 15. In 18 SHAs, these devices were used for determining incentive and penalty schedules for payments on newly paved roads.

The study also examined the initial roughness of a pavement section to determine if it had any effect on long-term performance. The University of Wyoming and the Wyoming Department of Transportation (WYDOT) examined the effect of initial smoothness of asphalt pavements on roughness measurements collected after the sections had been in service for a few years.

Test sections selected from interstate projects that had been rehabilitated between 1988 and 1992 were also evaluated. Pavement roughness data were obtained from these test sections and stored in a computerized database. A statistical analysis was performed on all data. Each project was divided into half-mile test sections, giving a total of 884 test sections. Average daily traffic (ADT), truck traffic, equivalent single axle loads (ESALs) and previous roughness data for these test sections were also collected.

After data collection, a comprehensive data analysis was performed. This analysis examined the relationship between initial and future (*i.e.*, current) IRI measurements, generated a regression relationship for each chart and performed the Mann-Whitney test (a non-parametric test based on the rank ordering of observations) on all data.[8]

Scatter graphs of the data were developed to see if any trends emerged. An upward trend on all asphalt test sections showed that the initial IRI measurements were correlated with future roughness values. A statistical analysis was

TABLE 2.
Summary of the Arizona Department of Transportation Study

	Ride Quality Measurement Device			
Category	**Profilometer**	**Roughness Surveyor**	**Ride Meter**	**Profilograph**
Quality of Roughness Data				
Repeatability	1	2	2	3
Accuracy & Reproducibility	1	2	3	2
Speed Dependency	2	1	3	2
Instrument Precision & Reliability				
Precision	1	2	3	4
Reliability	1	2	1	1
Distance Accuracy	1	1	1	2
Sensitivity to Calibration	1	3	3	2
Operating Restrictions				
Environmental Effects	2	3	1	2
Traffic Interference	1	1	1	2
Operating Speeds	1	1	1	2
Setup & Operating Complexities	2	1	1	3
Equipment Durability	1	3	2	2
Automated Data Collection & Processing				
Computer Compatibility	1	2	3	4
Availability & Quality of On-Board Data	1	2	3	4
Equipment Versatility	1	2	2	3
Cost	3	2	1	1
Overall	1	4	2	3

Note: Numbers are used to rank the devices. A 1 represents a device as being the best; a 4 represents the lowest rank. If the same number is given for two or more devices, these devices are ranked equivalently.

then performed, using the Mann-Whitney test. Initial IRI measurements were statistically tested against future IRI values to determine if initially smoother pavements remained smoother over time. The Mann-Whitney test indicated that the two groups (*i.e.*, initially smoother and initially rougher) were statistically different over time, a finding that established that initially smoother sections performed better than initially rougher sections.[8] A more recent study of over 200 asphalt concrete and PCC pavement projects in ten states tends to support the conclusions that initial smoothness may have a positive effect on future smoothness, and that higher initial smoothness may lead to longer pavement life.[9]

Colorado Department of Transportation Study. The Colorado Department of Transportation (DOT) began to develop a ride quality specification during the 1992 and 1993 paving seasons.[10] The specification was based on a rolling profilograph. A blanking band of 0.1 inches was used, which is more stringent than the blanking band of 0.2 inches used by most SHAs. The 0.1-inch blanking band was chosen because low amplitude vibrations caused by the vibratory rollers during construction would not be captured with a 0.2-inch blanking band range.

Beginning in 1994, Colorado used an incentive and penalty payment schedule on four projects using a 0.1-inch blanking band. In 1995, Shuler and Horton identified and reviewed perceived problems with the 1994 specification.[10] As a result, the asphalt industry and the Colorado DOT decided to make major changes in smoothness levels and incentive and penalty levels for each type of facility. Smoothness levels were adjusted by both industry and DOT officials for each facility. These facilities included rural interstates; urban interstates and other limited-access roads; rural two-lane roads; and urban and thin, single-lift roads. Criteria for rural interstates had the most stringent smoothness requirements, while two-lane urban interstates had lower requirements.

Shuler and Horton recommended that smoothness specifications be introduced gradually to allow the contracting community to learn methods and obtain the equipment necessary to achieve better riding pavements.[10] They also believed that smoothness specifications should include incentive and penalty clauses to encourage contractors to perform better than average work.

A Review of Paving & Ride Quality Practices

To determine the state of the art in paving and ride quality practices of state highway agencies in New England, a questionnaire was designed and used as a guide to conduct on-site meetings with each SHA in the region. In addition, the paving and ride quality practices of three other SHAs — Kansas, Michigan and Texas — were also reviewed.[11] A summary of the practices reported in use in New England appears in Table 3. A summary of the practices reported in use in Kansas, Michigan and Texas appears in Table 4.

Connecticut Department of Transportation (ConnDOT). ConnDOT uses hot mix bituminous asphalt (HMA) concrete as its primary paving material and does not recommend that a transfer vehicle be used. When resurfacing, ConnDOT engineers determine on-site if it is necessary to mill. If milling is found to be necessary, a depth is chosen and an HMA overlay of the desired thickness is put down. ConnDOT is currently developing and implementing a ride quality specification.[11]

ConnDOT has two automated road analyzing devices (ARANs) and a 25-foot profilograph. The ARAN uses laser and acoustic technologies mounted on the front of a van. It is equipped with a video camera to record the texture of the road surface and other road features. The profilograph was five to seven years old and had experienced limited use on a small number of projects since the purchase of the two ARANs. The ARANs are relatively new and will be used as the primary devices for initial ride quality measurement.

Contractors measure initial ride quality using a straightedge. After the completion of construction, ConnDOT anticipates using the ARAN to approve the contractor's work. Smoothness levels must comply with ConnDOT's written agreements that are set before construction. Initial ride quality data are collected less than 24 hours after completing all pavement operations. Measurements are recorded in IRI levels for the entire length of a project and will be taken in the direction of traffic in the right and left wheel paths in each driving lane.

Payment for each job is based on the IRI scale. Currently, the department does not expect to assess penalties for a job completed by a contractor at less than desired smoothness levels. However, the department does intend to pay bonuses for exceptionally low roughness levels.

Maine Department of Transportation (MDOT). BAC is used as the primary material for MDOT paving jobs. PCC has not been used by the MDOT since the 1970s. Resurfacing projects generally require a milling depth between 1.5 and 3 inches for most interstate highways, and HMA overlays are used. MDOT does not require the use of transfer vehicles during paving operations, although some contractors use them.

The contractor is responsible for maintaining a level of smoothness that is acceptable to the state agency during and after paving operations. Maine DOT does not test for initial ride quality; it uses its response-type ARAN only to test current road surfaces to determine if the roadway needs improvement. The response-type ARAN has replaced the road meter that was once used by this department. This ARAN differs from ConnDOT's device in that it uses accelerometers mounted on the axle of the vehicle to measure roughness. MDOT is considering the purchase of a newer version of the ARAN that uses laser and acoustic techniques, such as the one used by ConnDOT.

Massachusetts Highway Department (MHD). MHD has recently developed a ride quality specification.[11] MHD uses BAC as the primary

TABLE 3.
Summary of Current Paving & Ride Quality Practices in New England

	Agency						
Issues/Questions	**ConnDOT**	**MDOT**	**MHD**	**MTA**	**NHDOT**	**RIDOT**	**VAOT**
What type of pavement is most widely used?	BAC	BAC	BAC	BAC	BAC	BAC	BAC
Is a transfer vehicle used?	No	Up to contactor	Up to contractor	Yes	Up to contractor	Up to contractor	Up to contractor
Is there a ride quality specification?	No	No	Yes	Yes	Yes	No	No
When was the specification put in place?				December 1995	1995 (pilot)		
Is a specification being considered?	Yes	Yes				Yes	Yes
Does the specification include bonuses?	Yes	No	Yes	Yes	Yes	No	Yes
Does the specification include penalties?	No	No	Yes	Yes	Yes	No	Yes
What equipment is (or will be) used?	ARAN	ARAN	ARAN	Profiler	Profilometer	ARAN	Ride Meter
Is the equipment owned by the DOT?	Yes	Yes	Yes	No	Yes	No	Yes
What roughness measures are used?	IRI	IRI	IRI	IRI	Ride number	IRI	IRI
Percentage of pavement based on IRI values?	*IRI* *% Paid* <50 110 50-75 105 >75 100		See specification	*IRI* *% Paid* <50 110 50-75 105 76-90 100 91-100 75 101-120 50 >121 0	Ride number used. Pay adjustments are linear, not sptepped.		*IRI* *% Paid* <49 110 50-59 105 60-69 100 70-82 98 83-95 95 >96 90
Is a consultant used in specification review?	No	No	No	Yes	No	No	No
Milling limit?	Determined at site	1.5-3+ in.	2 in.	<3 in.	Determined at site	2-2.5 in.	Determined at site
What resurfacing practice is used?	HMA overlay	HMA overlay	HMA overlay	HMA overlay	HMA overlay	HMA overlay	HMA overlay
Bump size?	0.3 in.		0.3 in.	0.3 in.	0.2 in.	0.4 in.	0.3 in.
Length of straightedge?	10 ft.	10 ft.	10 ft.	10 ft.	10 ft.	10 ft.	10 ft.
Location of longitudinal profile testing?	Right & left wheel path in each lane	Right & left wheel path in each lane	Right & left wheel path in each lane	Right & left wheel path in each lane	Right & left wheel path in each lane	Right & left wheel path in each lane	Axle centerline deviation
Time limit for acceptance testing?	<24 hrs.		0-24 hrs.	0-24 hrs.	ASAP	ASAP	ASAP
Percentage of pavement segment evaluated?	100%		100%	100%	100%	Samples	100%
Who tests for smoothness during construction?	Contractor with straightedge	Contractor	Contractor with straightedge	MTA with consultant	Contractor with straightedge	Contractor with straightedge	Contractor with straightedge
Who approves ride quality levels at completion?	ConnDOT	Contractor	MHD	MTA	NHDOT	RIDOT	VAOT
Direction of ride quality testing?	Traffic flow	Traffic flow	Traffic flow	Traffic flow	Traffic flow	Traffic flow	Traffic flow

Notes: Milling limit — the thickness that existing pavement is milled before an overlay is applied (varies from project to project & in some cases no milling is required. Bump size — maximum deviation in roughness profile.

TABLE 4.
Summary of Current Paving & Ride Quality Practices in Other State Departments of Transportation

	Agency		
Issues/Questions	**Kansas DOT**	**Michigan DOT**	**Texas DOT**
What type of pavement is most widely used?	BAC & PCC	BAC & PCC	BAC & PCC
Is a transfer vehicle used?	Yes	Yes	Yes
Is there a ride quality specification?	Yes	Yes	Yes
When was the specification put in place?	1990		1993
Is a specification being considered?			
Does the specification include bonuses?	Yes	Yes	Yes
Does the specification include penalties?	Yes	Yes	Yes
What equipment is (or will be) used?	Profilograph	Profilometer & Profilograph	Profilograph
Is the equipment owned by the DOT?	Yes	Yes	Yes
What roughness measures are used?	Profile index (in./mile)	Ride Quality Index & Profile index (in./mile)	Profile index (in./mile)
Percentage of pavement based on IRI values?	Profile index used	Profile index used	Profile index used
Is a consultant used in specification review?	No	Yes	Yes
Milling limit?	Determined at site	1.25+ in.	Determined at site
What resurfacing practice is used?	HMA overlay	HMA overlay	
Bump size?	0.4 in.	0.3 in.	0.3 in.
Length of straightedge?	10 ft.	10 ft.	10 ft.
Location of longitudinal profile testing?	3 ft. from each lane edge	3 ft. from each lane edge	3 ft. from each lane edge
Time limit for acceptance testing?	<48 hrs.	ASAP	ASAP
Percentage of pavement segment evaluated?	100%	100%	100%
Who tests for smoothness during construction?	Contractor with straightedge	Contractor	Contractor
Who approves ride quality levels at completion?	DOT	DOT	DOT
Direction of ride quality testing?	Traffic flow	Traffic flow	Traffic flow

Notes: Milling limit — the thickness that existing pavement is milled before an overlay is applied (varies from project to project & in some cases no milling is required. Bump size — maximum deviation in roughness profile.

material for all paving jobs. Resurfacing projects generally require a milling depth of 2 inches, and HMA overlays are used. MHD does not require the use of a transfer vehicle during paving operations.

The contractor is responsible for producing a smooth pavement that is acceptable to the state agency during and after paving operations. MHD uses an ARAN device that is similar to ConnDOT's ARAN. The ARAN, mounted on the front of a van, uses laser and acoustic technologies. It is equipped with a video camera and a data recording center.

Initial ride quality data are collected less than 24 hours after completing all pavement operations. The entire project is divided into sections, and measurements are recorded in IRI levels for each section. The measurements are taken in the direction of traffic flow in the right and left wheel paths in each lane.

Payment for each job is based on the IRI scale. The department pays both bonuses and penalties for jobs completed by contractors. A pay scale determines the percentage that the contractor is paid, based on the IRI levels recorded by the ARAN.

Massachusetts Turnpike Authority (MTA). The MTA uses HMA concrete as its primary paving material. Unlike other SHAs, it requires that a transfer vehicle be used, having learned that the use of a transfer vehicle can improve pavement smoothness. When resurfacing, MTA engineers determine the milling depth for the project, which usually amounts to less than 3 inches, and an HMA overlay of the desired thickness is then put down. The MTA has developed a ride quality specification, which has been in use since December 1995.[11]

Contractors measure initial ride quality using a straightedge. However, the MTA measures smoothness levels throughout the project, using a profiler. Upon project completion, the MTA measures smoothness over the entire length of the project less than 24 hours after paving operations have ceased. Measurements are taken in the direction of traffic flow in the right and left wheel paths. Measurements are recorded in IRI levels.

Payment for each job is based on the IRI scale. The MTA pays both bonuses and penalties for jobs completed by contractors.

New Hampshire Department of Transportation (NHDOT). NHDOT uses HMA as its primary paving material. The use of a transfer vehicle is left up to the contractor. Resurfacing projects may or may not require milling; the determination is made on-site by an NHDOT engineer, and an HMA overlay of the desired thickness is used. NHDOT has conducted a pilot ride quality study as part of its quality control/quality assurance program which began in 1995 and has been recently fully implemented. The study, which was based on random sampling and statistical analyses, would permit an initial ride quality specification to be implemented.

NHDOT has found that a profilometer that uses an infrared sensor mounted on the front of the vehicle is the most accurate device for measuring initial ride quality. Unlike other devices used in New England, this type of profilometer does not measure smoothness using the IRI scale; instead, smoothness is measured using the ride number (RN). The data processing unit is different from that used in the ARAN.

Contractors measure initial ride quality using a straightedge. NHDOT tests smoothness levels on new pavements during construction, using a straightedge, and after all paving operations have been completed.

The ride number is measured for the entire length of a project. The measurement is taken in the direction of traffic flow in the right and left wheel paths in each driving lane. The department uses linear pay adjustments.

Rhode Island Department of Transportation (RIDOT). RIDOT uses HMA as its primary paving material. Use of a transfer vehicle is up to the contractor. When resurfacing, the agency generally requires a milling limit of between 2 and 2.5 inches, then an HMA overlay of the desired thickness is put down. RIDOT does not own or operate a ride quality measuring device. A local consulting firm operating an ARAN that uses laser and acoustic techniques performs the testing. RIDOT is currently developing and implementing a ride quality specification.

Contractors measure initial ride quality using a straightedge. After project completion, the agency contracts with the local firm to collect initial ride quality data. Smoothness levels must comply with RIDOT written agreements that are set before construction.

Measurements are recorded in IRI levels for the entire length of the project in the direction of traffic flow, in the right and left wheel paths in each driving lane. RIDOT has no bonus or penalty payment schedule.

Vermont Agency of Transportation (VAOT). The VAOT uses HMA concrete as its primary paving material. The use of a transfer vehicle during paving operations is up to the contractor. When resurfacing, VAOT engineers determine on-site if it is necessary to mill. If milling is found to be necessary, a depth is chosen and an HMA overlay of the desired thickness is put down.

VAOT measures initial ride quality with a ride meter. This device is a response-type road roughness system mounted on a trailer and pulled by a van owned by the agency. The data processing center is a laptop computer. VAOT is currently developing and implementing a ride quality specification.

Contractors measure initial ride quality using a straightedge. Initial ride quality data are collected less than 24 hours after completing all pavement operations. Measurements are calculated using the IRI scale, recorded from readings taken from the axle centerline deviation for the entire length of a project.

Payment for each job is based on the IRI scale. The VAOT pays both bonuses and penalties for jobs completed by contractors.

TABLE 5.
Kansas DOT Price Adjustment Scale

Profile Index (in./mile)	Price Adjustment ($)
<7.0	+152.00
7.2 to 10.0	+ 76.00
10.1 to 40.0	0.00
>40.1	- 2.03

Kansas State Department of Transportation (KDOT). KDOT uses both HMA and PCC in paving and requires the use of a transfer vehicle. When resurfacing, KDOT engineers determine on-site the appropriate depth, then an HMA overlay of the desired thickness is put down. KDOT has written ride quality specifications for both paving practices, which have been in use since 1990. The specification regarding the hot BAC method is relevant to paving practices in New England.

Contractors measure initial ride quality using a straightedge. Initial ride quality data are collected less than 48 hours after completing all pavement operations. KDOT uses a 25-foot profilograph that responds to the pavement's vertical displacement, called the profile of the roadway. The information is gathered in 0.1-mile sections and is recorded as a profile index (PI) expressed in inches/mile. Two runs are made at a distance of 2 to 3 feet from each lane edge, and the data are collected and reviewed. The average profile for each section is determined, and the contractor's price is adjusted according to Table 5.

Michigan Department of Transportation (MiDOT). MiDOT uses both HMA and PCC in paving and requires the use of a transfer vehicle. Resurfacing projects generally require a milling depth of greater than 1.25 inches; following milling an HMA overlay of the desired thickness is put down.

MiDOT has a 25-foot profilograph and a rapid-travel profilometer. Initial ride quality specifications have been written for both paving practices. The specification regarding the HMA method, with measurements taken with the profilometer, is relevant to paving practices in New England.

The rapid-travel profilometer is more frequently used than the 25-foot profilograph. It is similar to the laser-based profilometer that NHDOT uses. The rapid-travel profilometer expresses the ride quality of a pavement as ride quality index (RQI) units or inches per mile. The RQI is a measurement of the true profile of the roadway; this indicator selects statistical properties that relate to perceived vehicle user response.[3]

Initial ride quality data are collected less than 24 hours after completing all paving operations. As an incentive for contractors to develop a smooth riding pavement, MiDOT uses a pay scale that varies according to different levels of initial ride quality.

Texas Department of Transportation (TXDOT). TXDOT uses both HMA and PCC in paving and does not require the use of a transfer vehicle. Resurfacing projects generally require a milling depth that is determined on-site by a TXDOT engineer. TXDOT has written a ride quality specification to satisfy all profilographs and this specification has been in use since 1993. The specification refers to the HMA method.

Contractors measure initial ride quality using a straightedge. Initial ride quality data are collected less than 24 hours after completing all pavement operations. The profilograph resembles that of KDOT's in that it responds to the pavement's vertical displacement and, thus, records a profile of the roadway.

The contractor must test 0.1-mile sections of the project using a 25-foot profilograph, or a similar type of profilograph, yielding a PI expressed in inches per mile. Two runs are made at a distance of 2 to 3 feet from each lane edge, and the data are collected and reviewed. The average profile for each section is determined, and the contractor's price is adjusted according to a scale.

Summary

In helping SHAs in New England address issues and questions surrounding the development and implementation of a ride quality specification, a literature synthesis was conducted and documented. In addition, a survey of current ride quality and paving practices was performed and summarized.[11] Finally, a ride quality specification is proposed as a guide. This proposed specification is not meant to replace or change specifications developed by others, including the Federal Highway Administration (FHWA) or the American Association of State Highway and Transportation Officials (AASHTO).[12]

The proposed ride quality specification has four major sections. This specification should be used only as a guideline for SHAs when implementing a ride quality specification for hot mix asphalt pavements. This specification may or may not meet all the needs or expectations of all SHAs. This ride quality specification is proposed as a guide to assist those SHAs in New England that are in the process of formulating and implementing such specification. While it is recognized that some SHAs are further along in the process than others, this proposed specification may be more useful and instructive to those SHAs that are in the early stages of the process. It should also be noted that this ride quality specification is proposed for use on highway projects with flexible pavements, including an HMA wearing surface.

Some of the following items should be considered in developing the specification:

- The type of surface to be measured;
- A proposed schedule for data collection;
- The type of paving practices used on projects;
- The types of projects not subject to the specification; and,
- Sections of the project that are to be excluded from data collection.

Equipment used for data collection should be a Class I or Class II device (see Table 1 on page 53) as defined by the American Society for Testing Materials (ASTM-E950). Class I pavement smoothness measuring devices represent the highest standards of accuracy for measuring pavement smoothness and measure in intervals less than or equal to 1.0 foot. Direct profile measurement of a pavement is recorded with a Class II device. Laser and acoustic techniques, which must be calibrated in accordance to the manufacturer's specifications, are included in this classification. Measurements in this category are recorded every 2 feet or less. This device should also be able to calculate the IRI or another measurement parameter subject to the approval of the agency implementing the specification.

SHAs in the United States record initial ride quality using different measurement indicators. The IRI is a measurement that represents the response of a typical passenger vehicle as a result of a road's roughness.[13] The IRI is being considered by all SHAs in New England (with the exception of NHDOT) and was suggested in the proposed specification.

Ride quality bonuses and penalties are used by some agencies to encourage contractors to perform high-quality work. Bonus and penalty schedules should be applied to a ride quality specification. The values used in the proposed specification should be suitable for the New England region. SHAs should adjust the IRI values and bonus and penalty schedule as necessary.

Since the average IRI value may not sufficiently capture the variation in IRI over the entire length of the group of intervals, some SHAs may decide that a measure of variation (*e.g.*, standard deviation) should be used together with the average IRI. The IRI values and bonus and penalty schedules will vary from state to state and the IRI values in the proposed specification are only offered as a reference point, based on the experience of New England SHAs to date.

A Proposed RQ Specification

General. The contractor in cooperation with the SHA shall determine the smoothness of an HMA surface using a smoothness-measuring device. Smoothness data should be collected within 48 hours of completion of the paving portion of the project and the results should be presented to the SHA within 10 days. The costs incurred by the contractor to collect and analyze smoothness data should be included in the total project bid price.

All paving projects requiring a minimum of two courses in which the compacted depth of each course is 1.5 inches or greater are subject to this specification. Paving practices and procedures (including the number of courses and the thickness of each course) may vary from project to project within each state and from state to state. Consequently, some SHAs may desire to modify this provision in concert with their current paving procedures.

While the smoothness of all HMA pavement projects must be measured and corrected as necessary to meet minimum standards contained in this specification, the following projects are *not* subject to the pay adjustments proposed in this specification:

- Existing pavement that is milled, then resurfaced with less than 2 inches of HMA.
- Existing pavement that is cold recycled, then resurfaced with less than 2 inches of HMA.

An underlying aim of this provision is to encourage (to the extent possible) the highest level of ride quality on all paving projects regardless of surface thickness. However, it is recognized that overlays of less than 2 inches — even when applied over a prepared surface — may not be able to achieve the smoothness levels of a thicker overlay with multiple lifts.

Measuring smoothness on (or near) certain roadway features may require special treatment due to the presence of joints and certain geometric characteristics. Therefore, for simplicity and ease of implementation, these roadway sections have been excluded from this proposed specification:

- Bridge decks and joints;
- Acceleration and deceleration lanes;
- Shoulders and ramps;
- Pavement on horizontal curves which have a 900 feet *or* less centerline radius of curvature and pavement within the superelevation transition of curves; and,
- Existing roadways that are resurfaced and are less than 1,000 feet in length.

These project sections should be tested for smoothness with a straightedge or stringline.

Equipment. The data necessary to calculate the IRI will be collected with a smoothness-measuring device of the contractor's choice, subject to the approval of the SHA. This device should be a Class I or Class II device as defined by ASTM-E950. Where necessary and appropriate (as deemed by the SHA), a straightedge may be employed to supplement the use of the Class I or Class II device.

IRI. The final pavement surface shall be evaluated for smoothness using a device capable of calibrating the IRI as defined by the World Bank. Other measures, such as the RN or RQI may also be considered for use. The IRI is a mathematical summary of the longitudinal surface profile of a roadway in a wheel path. The IRI represents the response of a typical passenger vehicle as a result of a road's roughness. A value of zero is perfectly smooth pavement surface and values greater indicate rougher surfaces. The IRI is independent of distance traveled; thus, it can be calculated for any length of section. The IRI value is computed from the surface elevation data collected by a smoothness-measuring device in one wheel path.

Payment is based on the smoothness of the road measured in IRI units. The following steps will be carried out to obtain IRI measurements:

1. All data will be referenced by mile from the nearest mile post prior to the newly constructed section. If the section beginning coincides with a mile post, then all data will be referenced from the mile post one mile prior to the section.

2. Only mainline travel lanes will be included. Profile testing will be suspended 0.02 miles prior to the first and 0.02 miles after the last expansion joint on bridge decks. The exact location for the suspension and resumption will be determined and recorded in the field by the device operator. These locations will be used for all test runs in all mainline travel lanes.

3. Data collection will cease at the nearest mile post after the end of the newly constructed section.

4. All data will be collected at sampling intervals of a maximum of 2.0 feet along the length of the road in both the left and right wheel paths and will be reported in 0.1 mile intervals.

5. The IRI value for each lane will be measured in each wheel path at least twice.

6. The IRI data for the acceptable passes will be averaged for each lane and an overall average IRI will be determined for each lanes for each 0.1 mile interval. (For ease and simplification purposes, some SHAs may prefer to estimate an overall average IRI for the entire roadway project.)

Payment Adjustment Criteria. Payment on smoothness will be made for each 0.1 mile interval or group of intervals based on the average IRI. Any interval (or group of intervals) resulting in zero payment shall be removed, disposed of and replaced at the cost of the contractor. Payment factors are shown in Table 6. Because an average IRI value may not sufficiently capture the variation in IRI over the entire length of the group of intervals, some SHAs may decide that a measure of variation (*e.g.*, standard deviation) should be used together with the average IRI. These examples demonstrate the use of the standard deviation:

- A group of 0.1-mile intervals consisting of 500 tons of HMA has an IRI value of 70 with a standard deviation 22.0 (assuming that HMA is \$30/ton). The final payment factor is equal to ($PF_1 + PF_2$), or 100 + 0. Total payment is equal to the final payment factor divided by 100 times pavement cost times pavement quantity (in tons), or 1.00 × \$30.00 × 500 (\$15,000.00).
- A group of 0.1-mile intervals consisting of 500 tons of HMA has an IRI value of 70 with a standard deviation 9.0 (assuming that HMA is \$30/ton). The final payment factor is equal to ($PF_1 + PF_2$), or 100 + 6. Total payment is equal to the final payment factor divided by 100 times pavement cost times pavement quantity (in tons), or 1.06 × \$30.00 × 500 (\$15,900.00).

If the IRI at 0 percent payment is exceeded, construction must be suspended and will not be allowed to resume until corrective action is taken by the contractor.

Corrective Actions. After paving has ceased, all areas shall be inspected by an engineer and any area within a 15-foot straightedge having high points (bumps) or low points with deviations in excess of 0.3 inches should be corrected regardless of the IRI value.

The corrective method(s) chosen by the contractor shall be subject to the approval of the engineer and shall be performed at the contractor's expense. The contractor shall retest any section where corrections were made to verify that the corrections have been made to the engineer's approval. Corrective actions might include:

- Demand grinding or use of other profiling devices;
- Removing and replacing the entire pavement thickness;
- Removing the surface by milling and applying a lift(s) of the specified surface course;
- Overlaying (not patching) with the specified surface course; or,
- Use the other methods that will provide the desired results.

TABLE 6.
Payment Factors

Percent Payment (PF_2)	StandardDeviation
+6%	0-10
+4%	10.1-15.0
+2%	15.1-20.0
0%	20.1-25.0
-2%	25.1-30.0
-4%	30.1-35.1
-6%	>35.1

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