TECH BRIEF

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Benefits of Balanced Mix Design: Evidence from State Implementation Efforts

This Technical Brief highlights the benefits of implementing Balanced Mix Design (BMD) for asphalt mixtures by State Departments of Transportation (DOTs). While the full impact of BMD requires time to quantify, data from States with several years of implementation demonstrate measurable improvements in pavement performance and service life. These findings offer agency and industry stakeholders valuable evidence to support broader adoption of BMD to enhance mixture durability, optimize the use of innovative and recycled materials, and improve long-term cost efficiency of asphalt pavements.

INTRODUCTION

The pursuit of more durable asphalt pavements has prompted a gradual shift in mix design methodologies. While traditional volumetric mix design methods are widely used by State DOTs, several studies have noted that volumetric properties alone do not consistently ensure pavement longevity, especially with the increased use of innovative and recycled materials. Research has shown that asphalt mixtures meeting volumetric criteria can still exhibit reduced cracking resistance or moisture susceptibility in the field.[1–3] These performance challenges have contributed in some cases to increased maintenance needs and higher life-cycle costs, prompting interest in BMD approaches.

BMD has emerged to address these durability challenges by integrating traditional volumetric criteria with performance-indicative mechanical testing.[4] This mix design approach not only enhances the ability to mitigate asphalt mixture distresses but also promotes the responsible and effective use of innovative and recycled materials.

Although quantifying the full benefits of BMD requires time, States that have recently implemented the approach are beginning to observe or quantify measurable improvements in pavement performance. This document presents case studies from Illinois, New Jersey, Texas, and Virginia, that highlight early performance successes and benefits. The findings support broader adoption of BMD, offering the ability for extended pavement lifespans, reduced maintenance needs, and more efficient infrastructure investment.

Linking Increased Cracking Resistance to Enhanced Asphalt Overlay Performance in Illinois

The Illinois Department of Transportation (IDOT) implemented the Hamburg Wheel Track Test (HWTT) in 2014 to evaluate the rutting resistance of asphalt mixtures both during mix design and at the start of production.[5] Prior to this, indirect tensile strength (ITS) and tensile strength ratio (TSR) had been used for several years to evaluate the moisture resistance of asphalt mixtures. Recognizing the need for a complementary test to evaluate cracking resistance, a research project was initiated in 2013 at the Illinois Center for Transportation (ICT) at the University of Illinois. This effort led to three research studies focusing on developing the Illinois Flexibility Index Test (I-FIT) (ICT R27-128), comparing early field performance with laboratory test properties (ICT R27-161), and identifying the long-term aging protocol for I-FIT (ICT R27-175).[6–9]

The ICT R27-161 study included nine overlay projects located in IDOT District 1 within the greater Chicago area. For these projects, loose asphalt mixture samples and field cores were collected and tested using I-FIT, HWTT, and other volumetric and performance test methods (e.g., overlay test (OT), flexural bending beam fatigue). There was no I-FIT Flexibility Index (FI) criteria for any of the asphalt mixtures included in this group of projects. In some cases, the asphalt binder replacement (ABR) from fractionated reclaimed asphalt pavement (FRAP) and/or reclaimed asphalt shingles (RAS) exceeded 45 percent. Other mixtures had ABR values as high as 30 percent. Each project included pre-construction and multi-year post-construction distress surveys to monitor pavement performance.

Following this study, IDOT started benchmarking asphalt mixtures statewide using I-FIT data from both laboratory- and plant-produced mixtures over multiple years. This effort transitioned in 2016 to the completion of eleven pilot projects using an I-FIT FI criterion after short-term aging. All pilot projects involved overlays over rigid-type bases (portland cement concrete or, in one case, a combination of brick, block, steel, or similar material). I-FIT testing was conducted during mix design, at the start of production, and on post-construction field cores, with core FI values corrected for thickness per ICT R27-128.[7] Pre-construction distress surveys were completed for most projects, and all have undergone annual post-construction distress surveys through 2025. Crack severity (low, medium, or high) was documented, and I-FIT testing was performed on cores collected annually for the first six years of service, including immediately after construction.

In 2022, IDOT fully implemented the I-FIT for both mix design and the start of production, incorporating criteria for short- and long-term aging, with the latter applicable only to surface course mixtures.[10]

Objective

In 2025, IDOT reviewed the pavement performance data of the 2016 I-FIT pilot projects and ICT R27-161 study projects and compared those results with corresponding core and production FI results. The objective was to identify potential trends and correlations between pavement performance and I-FIT FI values.

Methodology

IDOT evaluates pavement performance using the Condition Rating Survey (CRS), which assigns numeric value to pavement sections ranging between 9.0 for new surfaces and 1.0 for non-traversable, failed surfaces. Primary distresses like type and severity of cracking, international roughness index, and rut depth affect the CRS value for asphalt-surfaced roads. IDOT determines CRS values annually for interstate roads and biennially for non-interstate roads.

For the 2025 review, CRS data were compiled for the 2016 I-FIT pilot projects and the ICT R27-161 study projects. All 2016 pilot projects had CRS values above 6.5. For the R27-161 projects, biennial CRS values were analyzed to estimate the number of years to reach a CRS value near 6.5. The average annual change in CRS (ΔCRS) was calculated using Eq. 1:

$$\Delta CRS = \frac{9.0 - CRS_{current}}{CRS\ Year - Overlay\ Year} \qquad \text{Eq. 1}$$

where $CRS_{current}$ is the most recent CRS value (e.g., 7.0), $CRS\ Year$ is the year of the most recent CRS evaluation (e.g., 2024), and $Overlay\ Year$ is the year the overlay was completed. A smaller ΔCRS indicates a slower rate of deterioration, whereas a larger ΔCRS reflects more rapid performance decline. Key assumptions in this review include:

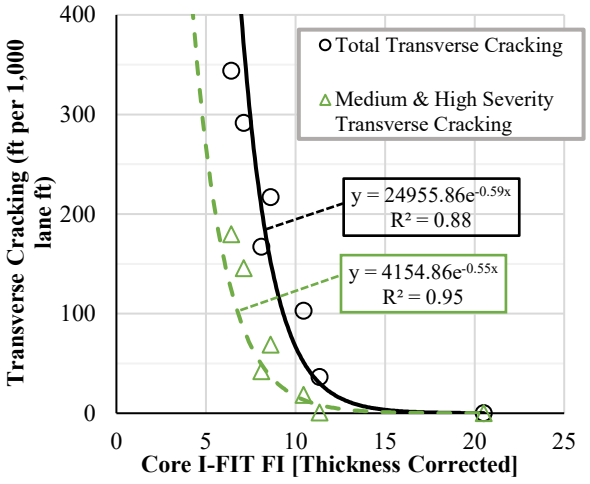
- For projects with multiple surface mixtures, FI and CRS values were averaged.
- If a project had two surface mixtures but only one FI value, that value was used.
- One 2016 I-FIT pilot project was excluded because a preservation treatment was applied several years into service.
- One R27-161 project and one 2016 I-FIT pilot project were excluded from the combined analysis due to missing production data for their surface mixtures.

Data Analysis and Findings

The 2016 I-FIT pilot projects included annual coring for I-FIT evaluation and distress surveys. Yearly FI values and transverse cracking measurements were averaged and are summarized in Figure 1. The y-axis represents transverse cracking in feet per 1,000 lane feet, reflecting the cumulative length of transverse cracking over that distance. For example, one full-width transverse crack every 100 feet in a 12-foot-wide lane would yield a value of 120 feet per 1,000 lane feet. The x-axis shows the average core FI values corrected for thickness per the ICT R27-128 study.[7]

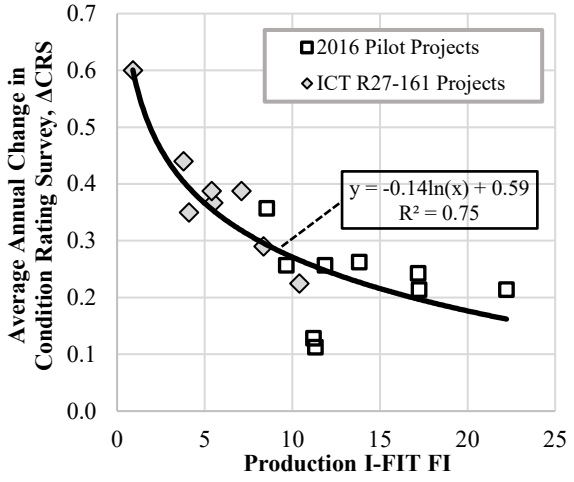
Figure 1 shows that over six years of service, the average core FI reduced by approximately 69 percent. The total as well as the medium and high severity transverse cracking exhibited a nonlinear inverse correlation with the average core FI, as shown by the trendlines. In addition, using Eq. 1 and measured CRS values, an average ΔCRS of 0.23 was calculated for these projects, which is lower than the average standard ΔCRS of 0.37 predicted by the IDOT's deterioration models for asphalt overlays of rigid-type bases. Thus, indicating a better field performance and a 37 percent reduction in the ΔCRS.

The combined data set for the 2016 I-FIT pilot and R27-161 projects was also analyzed using the production FI values obtained from loose asphalt mixture samples. The relationship between ΔCRS and production FI for each project is shown in Figure 2. Production FI values varied from less than 5.0 to greater than 15.0, with R27-161 projects exempt from minimum FI criteria during production. A nonlinear inverse relationship between ΔCRS and production FI was observed, indicating higher production FI values corresponded with lower rates of CRS deterioration, and thus better pavement performance.



Source: @ IDOT

Figure 1. 2016 I-FIT pilot projects average yearly core FI versus average yearly transverse cracking in IL.



Source: @ IDOT

Figure 2. Relationship between production FI and Δ*CRS* for I-FIT field projects in IL.

Increasing I-FIT FI from 3 to 8 reduces pavement deterioration rates for IDOT by 31 percent.

Key Takeaways

Data from these asphalt overlay projects confirm that cracking resistance, as measured by the I-FIT FI, is inversely related to changes in CRS. Asphalt mixtures with higher FI values generally exhibited reduced transverse cracking and slower pavement deterioration, aligning with what IDOT has observed in the field.

These findings have validated the agency's expectations and are informing ongoing refinements to their BMD specifications. IDOT plans to continue monitoring these field projects, using the data to support future design decisions and further improve long-term pavement performance.

Applying BMD to Enhance Pavement Perforamnce Across New Jersey

New Jersey DOT (NJDOT) began adoption of Superpave in the mid-1990s and fully implemented in 2001 standard specifications with an initial design compaction level of 125 gyrations (N_{design}) for pavements on very high traffic roadways maintained by NJDOT. The resulting dense-graded asphalt mixtures had low binder contents and coarse gradations, making them difficult to compact, prone to cracking, and often resulting in open and raveling longitudinal construction joints. To address these deficiencies, NJDOT progressively reduced N_{design} to 100 and, by 2014, to 75 and 50 gyrations for medium- and low-traffic volume applications, respectively. While these adjustments improved in-place density and constructability, concerns regarding durability remained due to the lack of implementable performance-indicative tests, prompting the use of proprietary high-performance mixtures on critical projects.[11]

To overcome cost and supply constraints associated with proprietary mixtures, NJDOT collaborated with academia and industry partners to develop performance-engineered

alternatives with continued support from different groups within the agency regarding the upfront research, resultant specification development, and follow-up efforts in pilot projects and into full adoption. This effort led to the introduction of BMD mixtures to improve durability and longevity of asphalt pavements, while also maintaining mixture's resistance to rutting. These asphalt mixtures retain essential volumetric properties while incorporating performance–indicative tests especially for rutting and cracking. These tests aim to reflect in-service conditions and typical failure mechanisms, helping to better characterize mixture performance. The BMD initiative was formally implemented in 2007 and has since evolved into a key component of NJDOT's network-level pavement management strategy.[11,12]

NJDOT specifies six BMD mixtures, each tailored to address specific structural and functional performance needs as summarized in Table 1: High-Performance Thin Overlay (HPTO), Binder-Rich Intermediate Course (BRIC), Binder-Rich Base Course (BRBC), Hot Mix Asphalt High RAP (HRAP), Bridge Deck Waterproof Surface Course (BDWSC), and Ultra-High Performance Thin Overlay (Ultra-HPTO).[10,13]

Performance criteria for these asphalt mixtures were initially derived by reverse-engineering proprietary high-performance mixtures and subsequently replicating their performance using locally available aggregates and polymer-modified asphalt binders. This process was guided not only by research and laboratory testing but also by field observations and practical engineering judgment. Investigations of premature cracking in composite pavements also led to adjustments in interlayer designs (by improving crack resistance and optimizing flexibility) based on how pavements performed in the field. To integrate these asphalt mixtures into quality assurance processes, NJDOT began piloting surrogate tests in 2023, including the Indirect Tensile Cracking Test (IDT-CT; also known as IDEAL-CT) and the High-Temperature Indirect Tensile (HT-IDT) test for cracking and rutting evaluation, respectively.[14–16]

Integration of BMD with Pavement Preservation Program for Network-Level Performance Optimization

Over the past two decades, NJDOT has transitioned from a reactive pavement maintenance approach to a proactive asset management strategy that emphasizes durability, cost-effectiveness, and performance accountability. A key component of this transformation is the integration of BMD into the pavement preservation program. This integrated framework leverages performance-based asphalt mixture specifications and condition-driven treatment selection to extend pavement life and optimize network-level pavement conditions.

The integration of BMD into NJDOT's asset management framework has been both strategic and data driven. Robust and sustained capital investment has enabled NJDOT to proactively schedule preservation treatments before structural degradation occurs. For example, HPTO mixtures are used on pavements in fair to good condition as part of a "preserve the good" strategy, while more robust BMD systems such as BRIC, stone matrix asphalt (SMA), and BRBC are used to rehabilitate structurally deficient composite pavements. These BMD treatments are supplemented by various preservation activities that include chip seals, microsurfacing, and ultra-thin friction courses to improve service life and cost efficiency.

Table 1. BMD Mixtures Adopted by NJDOT (2007–2024).

Mixture Type	Spec. First Issued[a]	Key Mechanical Tests and Criteria Used[b]	Primary Distress(es) Addressed	Typical Layer Thickness
Bridge Deck Waterproof Surface Course	2007	▪ APA rut depth ≤ 3 mm @ 8,000 cycles. ▪ Fatigue life ≥ 100,000 cycles @ 1500 microstrain (endurance limit check).	Bottom-up fatigue cracking and rutting over Bridge Deck	2 inches
High Performance Thin Overlay (HPTO)	2007	▪ APA rut depth ≤ 4 mm (design) / ≤ 5 mm (production) @ 8,000 cycles. ▪ OT ≥ 600 cycles.	Surface-initiated rutting; reflective and block cracking.	1 inch (part of pavement preservation program).
Binder-Rich Intermediate Course (BRIC)	2009	▪ APA rut depth ≤ 6 mm @ 8,000 cycles. ▪ OT ≥ 700 cycles (design) / ≥ 650 cycles (production). ▪ Asphalt binder content ≥ 7.4 percent.	Reflective cracking.	1 inch interlayer.
Binder-Rich Base Course (BRBC)	2009	▪ APA rut depth ≤ 5 mm @ 8,000 cycles. ▪ Fatigue life ≥ 100 million cycles @ 100 microstrain (endurance limit check).	Bottom-up fatigue cracking and rutting over rubblized PCC.	≥ 3 inches (project-specific)

Hot Mix Asphalt High RAP (HRAP)	2012	▪ APA rut depth @ 8,000 cycles.
		  ▪ PG 64-22 mixes ≤ 7 mm.
		  ▪ PG 76-22 mixes ≤ 4 mm.
		▪ OT
		  ▪ PG 64-22 mixes ≥ 150 cycles (surface) / ≥ 100 cycles (intermediate).
		  ▪ PG 76-22 mixes ≥ 175 cycles (surface) / ≥ 125 cycles (intermediate).
			Fatigue cracking and rutting in dense-graded mixes with ≥ 20 percent RAP (surface) or ≥ 30 percent RAP (intermediate/base)	1.25–1.5 inch for 9.5 mm surface layers; 2–3 inches for intermediate /base layers.

Ultra-High Performance Thin Overlay (Ultra-HPTO)	2024	▪ APA rut depth ≤ 3 mm @ 8,000 cycles. ▪ OT ≥ 2,500 cycles.	Surface-initiated rutting; reflective cracking over concrete pavement.	1 inch (part of pavement preservation program).

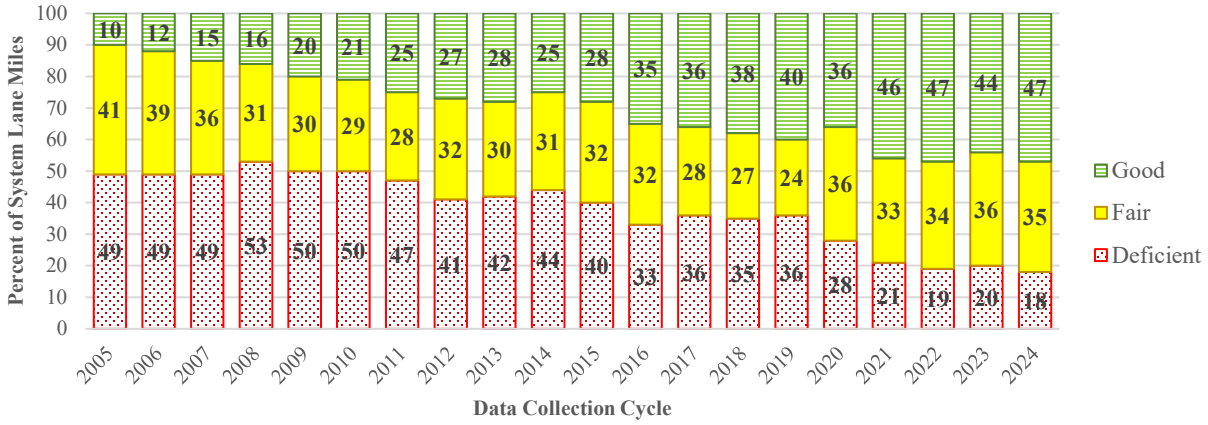
[a] Year the first NJDOT special provision was issued.
[b] APA = Asphalt Pavement Analyzer test (AASHTO T 340); OT = Texas Overlay Tester (NJDOT B-10); Fatigue life = repeated flexural bending test (AASHTO T 321).

Documented Network-Level Benefits

The implementation of BMD, combined with a strategic pavement preservation program and the introduction of a smoothness specification with incentives and disincentives beginning in 2007, has led to quantifiable improvements across NJ's state highway system. Figure 3 illustrates the condition trends of the NJ State highway system. Between 2005 and 2024, the proportion of state-maintained lane-miles classified as "Good" condition increased from 10 to 47 percent, while "Deficient" mileage dropped from 49 to 18 percent. This reversal in network condition represents a 370 percent increase in pavements rated Good and a 63 percent reduction in those rated deficient.

Although the BMD-supported preservation program began in 2007, measurable network-level improvements were observed only after several years. By 2022, NJDOT achieved its state-of-good-repair goal of maintaining at least 80 percent of the pavement network in Acceptable (Good and Fair) condition and less than 20 percent in Deficient condition. This milestone, reached 16 years after BMD program's inception, reflects the effectiveness of BMD and preservation strategies rather than increased in overall capital funding.

These gains are attributable to NJ leadership's robust and sustained pavement funding, as well as NJDOT's implementation of BMD-supported overlay systems, ride quality specifications, and preservation treatments.



Source: @ NJDOT Pavement Management System

Figure 3. Multi-year status of NJ State highway system.[11]

HPTO, introduced as part of the BMD program, delivers approximately 10 years of service life at a 1-inch thickness, outperforming traditional 2-inch mill-and-fill overlays with Superpave mixtures, which typically last around eight years. More structurally demanding applications, such as composite pavement rehabilitation, utilize BRIC plus SMA systems, which have demonstrated service lives exceeding 15 years, effectively doubling treatment cycles and reducing the frequency of major interventions. Ultra-HPTO is expected to provide additional life extension for the preservation of old concrete and composite pavements.

In addition to network-level performance improvements, NJDOT's approach has delivered cost benefits. The use of thinner, higher-performing overlays like HPTO has allowed the department to treat more lane-miles per dollar invested, enabling a more efficient allocation of capital. Moreover, the introduction of performance specifications has diversified the supplier base, lessening the need for proprietary mixtures while ensuring more resilient local supply chains.

Annual pavement condition surveys, specifically the IRI and Surface Distress Index (SDI) data, are used to validate the effectiveness of these treatments. In recent analyses, BMD performance indicators such as IDEAL-CT have shown strong correlation with observed field performance, reinforcing NJDOT's 2023 decision to transition to surrogate tests for production acceptance.

Since 2007, NJDOT's implementation of BMD increased pavements rated "Good" by 370 percent and reduced "Deficient" mileage by 63 percent.

Key Takeaways

In summary, NJDOT's integration of BMD with data-driven preservation planning has transformed its pavement management program. While the benefits may not have been immediately evident during early implementation, the long-term impact on system-wide performance has proven significant. This approach has delivered sustained improvements in condition metrics, service life, and cost-efficiency, establishing a model for other State DOTs seeking to modernize their asphalt pavement strategies.

Extending Pavement Life of Texas Mixtures Through BMD: Test Track Insights

In 2018, the Texas Department of Transportation (TxDOT) developed a special provision for BMD with the goal of improving the durability and longevity of asphalt mixtures through balanced performance. The provision included the HWTT and OT to evaluate rutting and cracking resistance with criteria primarily derived from prior laboratory studies. To validate these test criteria and assess potential performance benefits, TxDOT initiated a field experiment at the National Center for Asphalt Technology (NCAT) Test Track to compare the field performance of surface asphalt mixtures designed using volumetric mix design (VMD) and BMD approaches.[17] The experiment included two test sections: S10 BMD and S11 VMD, both constructed as 2.5-inch mill-and-inlays over existing asphalt pavements with approximately 15 to 20 percent fatigue cracking.

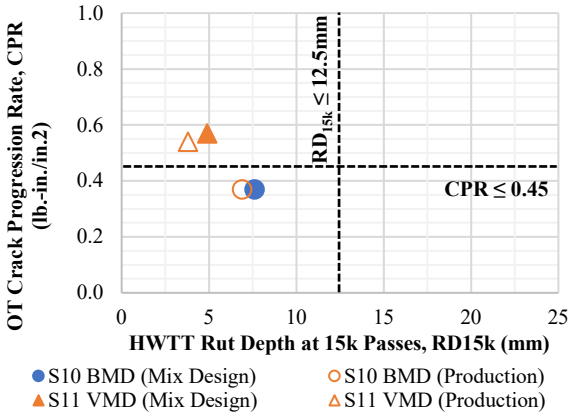
Mix Design and Production Results

The S11 VMD mixture was designed following TxDOT's dense-graded hot mix asphalt specifications, whereas the S10 BMD mixture was designed according to the Volumetric Design with BMD Verification approach as per AASHTO PP 105-24.[1,18] As part of the mix design process, the BMD mixture was tested with the HWTT, per AASHTO T 324, for rutting evaluation and the OT per Tex-248-F for cracking evaluation.[19,20] Both mixtures used the same components, including a PG 70-22 styrene butadiene styrene modified binder, FRAP, and a blend of granite and dolomitic limestone. However, they differed in aggregate gradation and volumetric properties, as summarized in Table 2. Notably, the S10 BMD mixture had 0.8 percent higher asphalt content and 2.0 percent higher voids in mineral aggregate (VMA) compared to the S11 VMD mixture, while maintaining the design air voids and recycled binder ratio.

Figure 4 shows the HWTT and OT performance diagram of the two mixtures from mix design and production. The dashed lines present TxDOT's test criteria, with a maximum HWTT rut depth of 12.5mm at 15,000 passes for PG 70-22 binder and a maximum OT crack progression rate (CPR) of 0.45 lb.-in./in.^{2}. The S11 VMD mixture exhibited good rutting resistance but poor cracking resistance, while the S10 BMD mixture achieved balanced performance due to higher asphalt content.

Table 2. Texas Mix Design Volumetrics (Data from Ref. 17).

Volumetric Properties	S11 VMD	S10 BMD
Design Gyration	50	50
Asphalt Content (percent)	4.7	5.5
Reclaimed Binder Ratio, RBR (percent)	20	20
Air Voids (percent)	4.0	4.0
Voids in Mineral Aggregate, VMA (percent)	15.0	16.6
Voids Filled with Asphalt, VFA (percent)	73.3	75.9
Dust Proportion, DP	1.0	0.9



Notes: BMD = balanced mix design; VMD = volumetric mix design.

Figure 4. Performance diagram for Texas mixtures (Data from Ref. 17).

Field Performance

After construction, the two sections underwent accelerated pavement testing for up to 20 million equivalent single axle loads (MESALs) at the Test Track. Both sections showed satisfactory rutting performance with approximately 0.3 inches of rutting, well within the 0.5-inch criterion. As shown in Figure 5, the S11 VMD section developed cracking at 5.5 MESALs and reached 20 percent cracked lane area, quantified following the Moving Ahead for Progress in the 21st Century Act (MAP-21) procedure, by 14.5 MESALs.[21] The section was milled after reaching 15.8 MESALs. The S10 BMD section developed cracking at approximately 9.0 MESALs, progressing to 11.0 percent cracked lane area at 20 MESALs. Overall, the field performance of these two sections matched well with the HWTT and OT results in Figure 4. Using 20 percent as the cracking criterion following MAP-21 recommendations, the S11 VMD section had a service life of 14.5 MESALs, while the S10 BMD section lasted over 20 MESALs, extending pavement life by at least 5.5 MESALs (about 38 percent) for BMD over VMD.

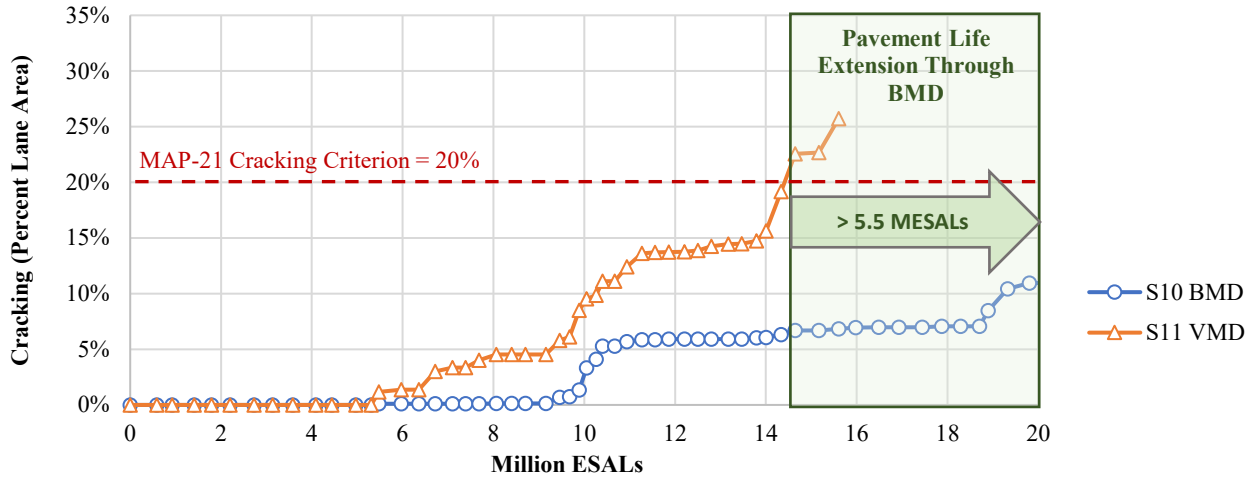
Cost Comparison

A material cost analysis shows that due to the higher asphalt binder content, the S10 BMD mixture is 6 percent more expensive than the S11 VMD mixture. However, from a life-cycle cost perspective, the S10 BMD mixture is found to be 17 percent more cost-effective, assuming a conservative service life of 20 MESALs compared to 14.5 MESALs for the S11 VMD mixture.[22]

TxDOT's BMD mixture at the test track extended pavement life by at least 38 percent with a reduced life-cycle cost of 17 percent.

Key Takeaways

This case study highlights the improved pavement performance of a BMD test section compared to a VMD test section at the NCAT Test Track. By adjusting aggregate gradation and adding asphalt binder, the BMD mixture achieved balanced rutting and cracking resistance while meeting volumetric requirements.



Notes: BMD = balanced mix design; VMD = volumetric mix design; ESAL = equivalent single axle loads.

Figure 5. Field cracking data at NCAT Test Track (data from Ref. 17)

Field performance data reveal a pavement life extension of at least 5.5 MESALs for the BMD section, which results in life-cycle cost savings despite an increase in material cost of the mixture compared to the VMD section. While this case study focused on asphalt binder and gradation adjustments, BMD mixtures can also be optimized through other approaches, such as the use of asphalt binders with different continuous grades and asphalt additives. These additional adjustments offer further flexibility for State DOTs to modify mixtures to local materials and performance needs.

Higher Cracking Test Criterion and Its Impact on Pavement Performance in Virginia

The Virginia Department of Transportation (VDOT) began exploring the implementation of BMD in 2018 to address three primary issues: (1) poor cracking performance of surface asphalt mixtures resulting in reduced service life; (2) concerns that mixtures were under-asphalted; and (3) industry interest in using higher RAP contents (greater than 30 percent) in urban surface mixtures.

Beginning in 2017, researchers at the Virginia Transportation Research Council (VTRC) initiated a study to benchmark the performance of asphalt mixtures produced and sampled in 2015 to support proposed pilot projects with mixtures containing higher RAP contents.[23,24] Three performance-indicative tests addressing different modes of distress were selected for inclusion in the BMD approach: (1) the Cantabro mass loss test to assess durability potential; (2) the IDEAL-CT at intermediate temperature to assess cracking resistance; and (3) the APA test to assess rutting susceptibility. Initial test criteria were set based on benchmark data to promote improvement in about 50 percent of VDOT's dense-graded, non-polymer-modified surface asphalt mixtures. Test criteria comprised a maximum 7.5 percent mass loss for the Cantabro test, a minimum cracking tolerance index (CT_{Index}) of 70 for the IDEAL-CT at 25°C, and a maximum 8.0 mm APA rut depth at 64°C.

Subsequently, two VDOT BMD special provisions were drafted and revised for use in pilot projects: (1) *Special Provision for High Reclaimed Asphalt Pavement (RAP) Content Surface Mixtures Designed Using Performance Criteria,* and (2) *Special Provision for Dense Graded Surface Mixtures Designed Using Performance Criteria*. Between 2019 and 2020, a total of seven field trials were conducted to design, produce, and place BMD mixtures with varying RAP contents and binder grades, recycling agents, warm mix asphalt, fibers, and softening oils. A total of eight non-BMD control mixtures and eight BMD mixtures were paved.[24,25,26]

VDOT expanded BMD implementation through district-led pilot projects using maintenance resurfacing contracts.[27] In 2021, about 72,000 tons of BMD mixtures were placed across 10 contracts in five districts. The program grew to 222,000 tons in 2022, covering 13 contracts across all nine VDOT districts, with at least one BMD contract per district. Implementation continued in 2023 with 15 contracts totaling approximately 335,000 tons.

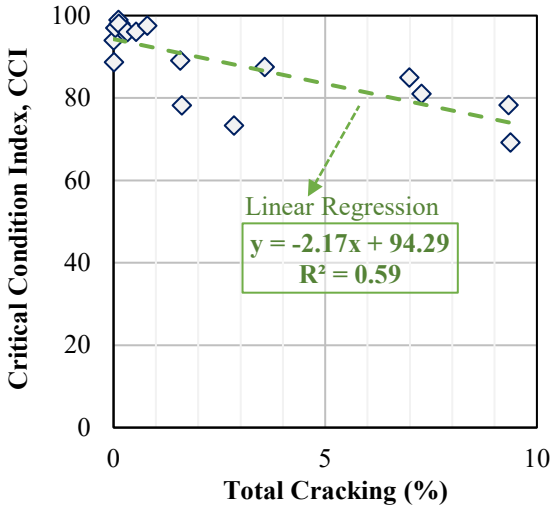
Building on these successes, VDOT fully implemented BMD in 2024 for all dense-graded, non-polymer modified surface asphalt mixtures paved under maintenance resurfacing contracts, totaling roughly 1.61 million tons, or 45.7% of all maintenance contract mixtures.

Assessing Performance Improvement

To confirm the initial BMD cracking test criteria, VTRC analyzed the performance of the eleven surface asphalt mixtures paved in 2015 and used to initially benchmark mixtures. Pavement condition surveys, Falling Weight Deflectometer testing, field visits, and core testing were conducted to assess the mixture properties and pavement conditions after eight years in service. In addition, information extracted from VDOT's Pavement Management System was analyzed. The performance of the mixtures was assessed relative to the initial mixture properties and the results of the BMD benchmark testing.

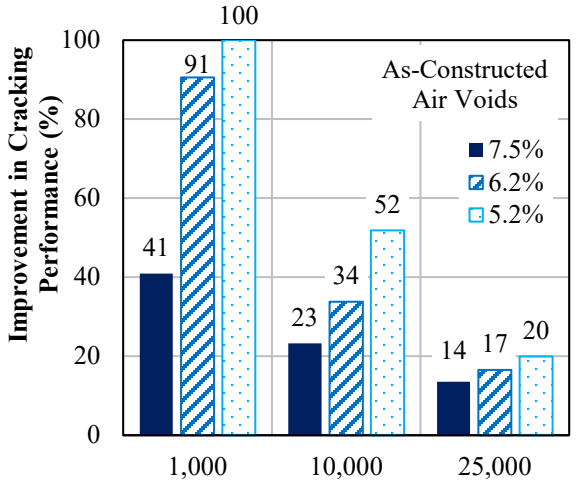
Using field data, a relationship between total cracking, defined as the area of all cracking divided by the lane area, and the critical condition index (CCI) was determined using linear regression. The CCI is a numerical scale from 0 to 100 used by VDOT to rate pavement condition, with 100 indicating a new surface and 0 complete failure. A CCI value below 60 indicates a deficient condition triggering the application of maintenance activities. The data in Figure 6, including multi-year condition assessments for some of the eleven mixtures, indicate that a 1 percent reduction in total cracking corresponds to an approximate 2.17-unit increase in CCI.[28]

Another regression model also based on the analysis of the 2015 mixtures, estimated pavement cracking using as-constructed air voids, average annual daily traffic (AADT), and the CT_{Index} of the reheated plant-produced mixtures.[28] Results in Figure 7 show that increasing CT_{Index} threshold from 70 to 100 can improve eight-year cracking performance by about 23 percent for a surface mixture with 10,000 AADT and 7.5 percent air voids.[28] VDOT initially set the CT_{Index} criterion at 70 based on experiences to date, with the production threshold is to be increased to 100 in 2026.



Source: @ VDOT

Figure 6. Total cracking versus CCI at 8 years in service for field sections associated with benchmarking mixtures. (CCI = 60 indicates a deficient condition)



Source: @ VDOT

Figure 7. Predicted cracking performance improvement at 8 years of service due to increasing CT_{Index} from 70 to 100. (Shown for three levels of as-constructed air voids and traffic loading)

Quantifying the Economic Impact

For initial cracking levels ranging from 1 to 20 percent, increasing the CT_{Index} from 70 to 100 reduces total cracking by 0.8 to 15.3 percent, as summarized in Table 3. The corresponding improvement in CCI was estimated using the established relationship between total cracking and pavement condition shown in Figure 6.[28]

The analysis of the CCI data for 0.1-mi pavement segments after 8 years of service (2024) showed that 14.4 percent were deficient, with CCI values less than or equal to 60 (Figure 8). This was assumed to be representative of the current distribution of Pavement Maintenance contract route conditions. If the average CCI increase of 5.2 units is applied to the data, only 9.9 percent of segments would remain deficient; indicating that about 4.2 percent of otherwise deficient segments would stay in adequate condition with a CT_{Index} increase from 70 to 100 during production. [28]

Extrapolating the 4.2 percent of non-deficient segments to the 1,516,067 tons let under Virginia's 2024 pavement maintenance contracts equates to about 63,000 tons of deferred surface asphalt mixtures. At an average cost of $109 per ton, this improvement in production CT_{Index} represents over $6.8 million in deferred costs for the analysis year (effectively freeing up 4.2 percent of the annual budget). These estimates assume that deficient segments are repaved and exclude preventative maintenance treatments. Additional savings are expected as improved cracking performance sustains CCI above 60. Nonetheless, continued monitoring of the 2015 and subsequent BMD mixtures (2019–2021) is needed to validate these projections.

Table 3. Improvement in CCI Resulting from an Increase in CT_{Index} from 70 to 100.

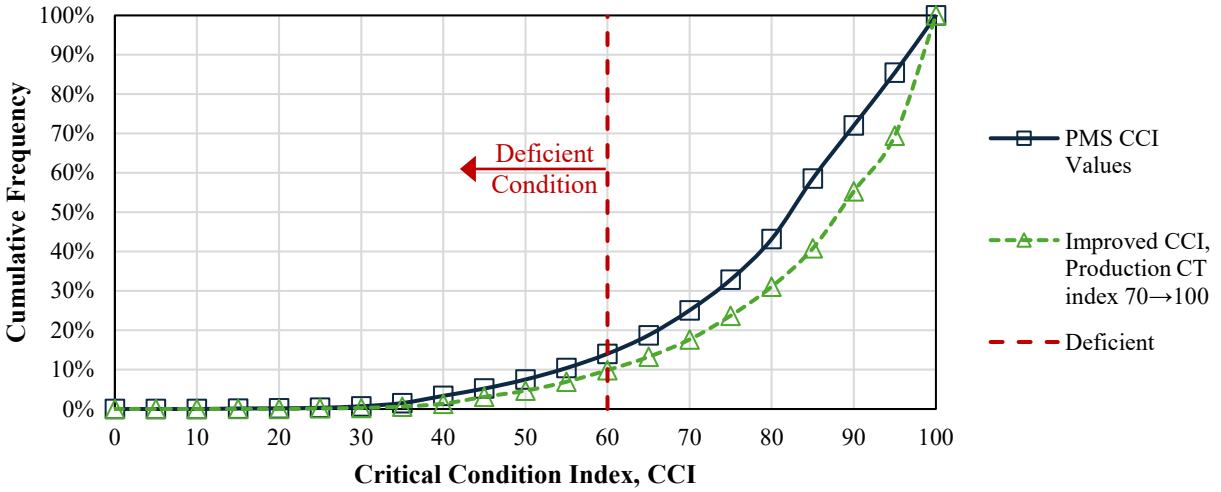
Estimated Total Cracking at CT_{Index} of 70 (%)[a]	Estimated Total Cracking by Increasing CT_{Index} to 100 (%)[a]	Difference (%)	Expected CCI Improvement[b]
1.0	0.8	0.2	0.5
3.0	2.3	0.7	1.5
5.0	3.8	1.2	2.5
7.0	5.4	1.6	3.5
10.0	7.7	2.3	5.1
13.0	10.0	3.0	6.6
15.0	11.5	3.5	7.6
18.0	13.8	4.2	9.1
20.0	15.3	4.7	10.1

[a]Estimated from relationship between pavement cracking at eight years of service, as-constructed air voids, average annual daily traffic, and CT_{Index} of reheated plant-produced mixtures.
[b]Determined from relationship in Figure 6. Average expected improvement in CCI = 5.2.

VDOT's BMD implementation showed a CT_{Index} increase from 70 to 100 improved cracking performance index by an average of 5.2 units and deferred over $6.8 million—4.2 percent of allocated budget—in maintenance costs.

Key Takeaways

VDOT's BMD projects demonstrate that asphalt mixtures with higher CT_{Index} values reduce cracking and extend pavement life. BMD also enables designers to optimize the use of RAP contents in surface mixtures without compromising performance, supporting more resource responsible use of recycled materials.[25,26] Field performance data confirm these benefits and guide ongoing refinements of the BMD specifications. Building on this success, VDOT plans to expand the application of BMD to polymer-modified asphalt mixtures for interstate and high-volume traffic routes, promoting longer-lasting asphalt pavements.



Source: @ VDOT

Figure 8. Shift in CCI cumulative frequency due to increase in CT_{Index} value from 70 to 100 during production. (Red dashed line marks a CCI of 60, the threshold for deficient segments)

Table 4. Summary of BMD Case Studies Demonstrating Performance and Economic Benefits.

State	Motivation for BMD Implementation	Methods Used to Establish Initial Test Criteria	Key Focus of Case Study	Main Findings	Impact/Benefit
Illinois	Improve mixture performance and reduce premature failures from the use of recycled materials while balancing stability and cracking resistance.	Accelerated load facility, pilot field studies, shadow testing, and multi-year performance monitoring.	Developed and Implemented I-FIT to evaluate cracking resistance of asphalt mixtures.	Found a strong inverse relationship between FI values and amount of transverse cracking.	Higher cracking resistance slowed pavement deterioration leading to extended pavement life.
New Jersey	Improve mixture durability and cracking performance beyond gyrations and volumetric adjustments.	Special Pavement Study 5 sections, pavement management system data, and monitoring of field projects.	Integrated BMD mixtures into a network-level pavement preservation program.	Shifted from a reactive to a proactive pavement preservation program.	Increased roads rated as "Good" by 370 percent and achieved the "state-of-good-repair" in 16 years.
Texas	Enhance durability and longevity of high-RAP asphalt mixtures and reduce premature failures.	Accelerated load facility, test track, field demonstration projects, and multi-year performance monitoring.	Conducted side-by-side BMD versus VMD comparison at a test track.	BMD mixture extended pavement life by 38 percent (at least 5.5 MESALs).	Despite 6 percent higher cost, BMD was 17 percent more cost-effective over its lifecycle.
Virginia	Increase asphalt mixture durability, while allowing for greater contractor innovation.	A combination of field performance monitoring and laboratory testing, and accelerated pavement testing.	Applied CT_{Index} to mix design and production of asphalt mixtures.	Increasing CT_{Index} during production (70 to 100) improved pavement condition and deferred maintenance, preserving about 4 percent of deficient segments.	Estimated $6.8M savings (4.2 percent of annual budget) and more durable, resource-efficient pavements.

Notes: BMD = Balanced Mix Design; CRS = Condition Rating Survey; CT_{Index} = Cracking Tolerance Index; MESALs = Million Equivalent Single Axle Loads; VMD = Volumetric Mix Design.

Overall Summary

The four case studies illustrate that the implementation of BMD can lead to measurable improvements in pavement performance and potentially provide life-cycle cost savings. Table 4 summarizes the key focus areas, findings, and outcomes from each State's implementation of BMD.

Conclusion

Quantifying the full benefits of BMD takes time, as measurable performance improvements typically emerge only after several years of in-service field data are available. Early findings from four lead States—Illinois, New Jersey, Texas, and Virginia—clearly indicate that BMD implementation can result in improved pavement performance and life-cycle cost savings. It is important to recognize that such improvements can sometimes coincide with other agency initiatives such as increased use of polymer-modified asphalt binders, increased asphalt binder contents, improved RAP management, or enhanced construction practices, which may also contribute to overall performance gains. The case studies presented in this document mainly highlighted performance observations from early pilot projects or controlled comparison studies where mixture design was the primary variable.

Each State applied a different approach to assess the benefits, yet all demonstrated that BMD leads to enhanced durability, extended service life, and reduced maintenance needs. The presented data demonstrate that the BMD approach is key to building more durable and cost-effective asphalt pavements.

While initial implementation involves commitment, collaboration, and investment in testing and data collection from all stakeholders, the long-term evidence shows a strong return on this collaborative effort. BMD is more than a technical enhancement to the mix design—it is a strategic shift in pavement management, enabling State DOTs to move from reactive maintenance toward proactive preservation and ensuring a better performing roadway network.

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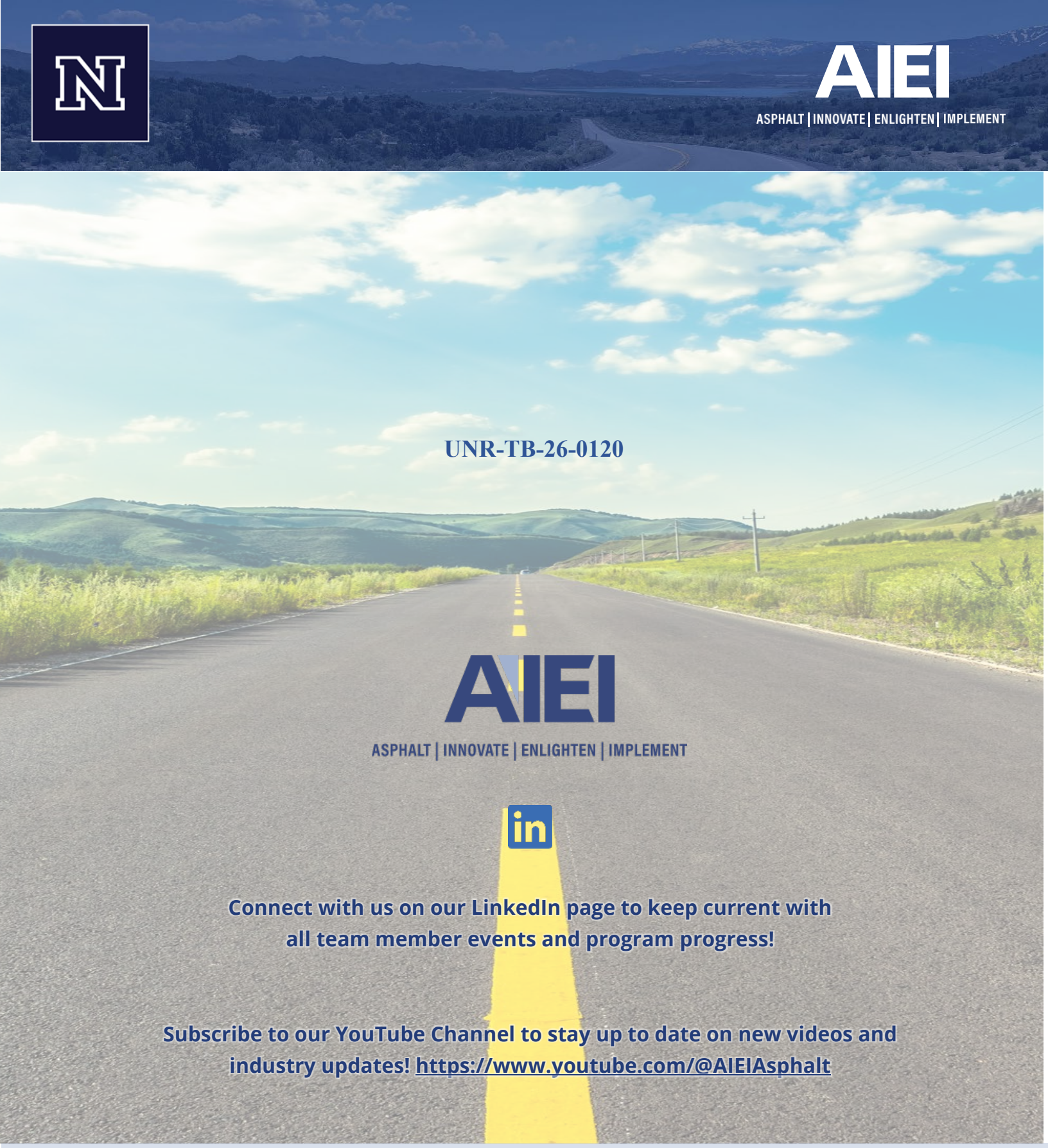

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