Figure 5 shows the effect of various network-disruption scenarios on percent change in network accessibility. It is shown in the figure that the percent change in network accessibility generally increases when more links are subjected to disruption. For example, the BN+C's percent decrease in network accessibility in the case of 2-link, 4-link, and 6-link disruption events were 0.01, 0.18, and 0.3, respectively, indicating that the network accessibility may decrease significantly as more and more links are disrupted due to natural and human-made network disruption events. The BN+BC network also showed a decrease in network accessibility as more links are disrupted with 4-link and 6-link disruption events causing a 0.01, 0.02, and 0.18 percent decrease in network accessibility. The BN+ABC network also showed a decrease in network accessibility as more links are disrupted with the 2-link and 4-link disruption events causing a 0.05 and 0.01 percent decrease in network accessibility. However, its 4-link and 6-link disruption scenarios led to an equal percent decrease in network accessibility. This result could be attributed to the implementation of multiple projects that may increase network resilience for accessibility reduction.

It is interesting to see in Figure 5 that for the same number of link disruption scenarios, the implementation of a higher number of LVR projects helps reduce network accessibility reduction. For instance, the 6-link disruption events of BN+C, BN+BC, and BN+ABC networks caused a 0.3, 0.18, and 0.01 percent decrease in network accessibility, respectively, compared with the base network no-disruption scenario. This result shows the importance of the simultaneous implementation of LVR projects in reducing the accessibility impacts of natural and human-made events. The BN+BC network showed an increase in network accessibility even after a 2-link disruption occurred, showing that LVR projects can help improve network accessibility after the disruption events damaged the LVR network and facilitate rescue mission in communities living inside the network influence areas.

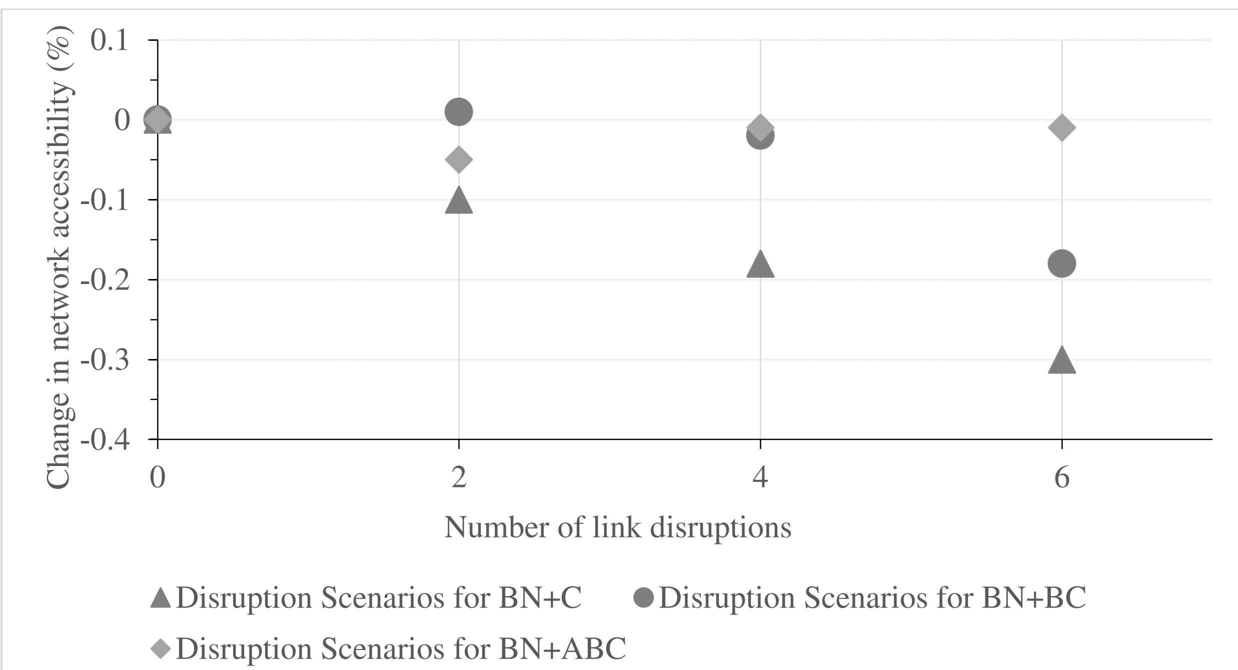

Figure 5. Percent change in network accessibility for various link disruption scenarios.

For the BN+ABC network case, the 4-link and the 6-link disruption scenarios have brought a lower reduction in network accessibility (i.e., 0.01%) compared to its 2-link disruption scenario (i.e., 0.05%). This result helps infrastructure decision-makers recognize that a higher number of disrupted links does not necessarily imply a higher percentage reduction in network accessibility. The spatial locations of the disrupted links and the LVR projects in the network may also determine the percent reduction in network accessibility.

6. SUMMARY AND CONCLUSIONS

This study presented a framework for prioritizing road projects based on their contribution to network accessibility. The developed framework was demonstrated using a low-volume road (LVR) network. The study results indicated that the spatial locations of LVR projects and stakeholders' preferences to the LVR projects affect the projects' contribution to the overall network accessibility.

An experimental network disruption simulation study was conducted considering different network disruption scenarios. As the simulation results indicated, the network accessibility could increase after network disruption events due to the implementation of LVR roadway projects. These results help investment decision-makers justify the importance of selecting the best LVR projects to maintain or even improve network accessibility after network disruption events (such as flooding and earthquake) damaged LVR networks in areas where those disruption events are widespread.

The developed framework is useful for prioritizing new roadway projects or roadway maintenance or rehabilitation projects. The framework is beneficial for selecting the best LVR projects for road networks such as rural road networks and low-volume road networks with a lower degree of connectivity among network nodes because a single roadway link may play a critical role in keeping the network connectivity and accessibility. In general, the study framework helps transportation planners and investment decision-makers prioritize infrastructure investments considering network accessibility and stakeholders' preferences. Decision-makers could also incorporate the developed framework into other multi-criteria decision-making frameworks that do not consider the roadway projects' accessibility impacts at the network level.

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ODOT Involvement with the NCAT Test Track and Task Groups

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ABSTRACT

Oklahoma Department of Transportation (ODOT) has been sponsoring the National Center of Asphalt Technology (NCAT) test track studies since its first inauguration cycle in 2000. In each cycle, ODOT had direct involvement in constructing Oklahoma sections with clearly defined research themes but also participated in group experiments. ODOT's participation and the benefits received from the track testing have been followed but not documented in a single place, and the benefits received from the track testing also needs to be documented and reported. In this paper, the ODOT's detailed participation, materials testing results, research focus and conclusions, potential benefits, and implementation of NCAT results in Oklahoma pavement projects are particularly presented.

Keywords: Oklahoma Department of Transportation (ODOT), National Center of Asphalt Technology (NCAT), test track, task group, benefits

1 INTRODUCTION

The NCAT Pavement Test Track has been successfully operated by the National Center for Asphalt Technology (NCAT) for almost two decades. The test track is funded and managed as a cooperative project, highway agencies, and industry sponsors with specific and shared research objectives by constructing real-world testing sections and monitoring their performance under accelerated trafficking, with the primary goal to improve their asphalt mix specifications, construction practices, and pavement design methods.

Oklahoma Department of Transportation (ODOT) has been sponsoring the NCAT test track studies since its first inauguration cycle in 2000. Thus far there were seven research cycles, 3 years per cycle. In each cycle, ODOT had direct involvement in constructing Oklahoma sections with clearly defined research themes but also participated in group experiments. ODOT's contribution is approximately $500,000 per year. To date, ODOT's participation has been followed but not documented in a single place, and the benefits received from the track testing also needs to be documented and reported.

In this paper, a comprehensive summary of ODOT's involvement at NCAT during the past 20 years is provided using data and information from ODOT Materials Division, NCAT published reports and personal interviews.

2 NCAT TEST TRACK AND GROUP FINDINGS

2.1 Background of the Track

The 1.7-mile test track (Figure 1), consisting of 46 200-ft. test sections, is an accelerated pavement testing facility that brings together real-world pavement construction with live heavy trafficking for rapid testing and analysis of asphalt pavements (NCAT, 2002). Sections are sponsored on three-year cycles. The first part of each cycle begins with building or replacing test sections, which normally takes about six months. Trafficking is applied over two years using a fleet of heavily loaded tractor-trailer rigs to provide the equivalent of 10 million 18,000-pound single-axle loads (ESALs). During the trafficking phase, the performance of the test sections is monitored using surface measurements and non-destructive structural response methods. Samples of the mixtures obtained during construction are tested and analyzed in NCAT's laboratory.

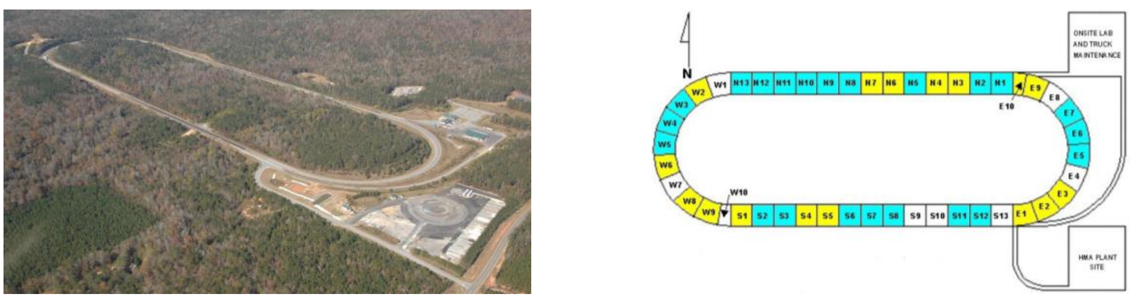

Figure 1 NCAT Test Track and Test Sections (NCAT, 2002)

2.2 Test Track Research Cycles

The first cycle began in 2000. Experiments in the inaugural cycle focused only on surface mixtures. Test sections were built with Stone Matrix Asphalt (SMA), Superpave, and Hveem mixes using a wide variety of aggregate types, gradations, and asphalt binders. The second cycle began in 2003 and continued the evaluation of twenty-four of the original test sections. New "structural experiments" included fourteen test sections with new surface layers and 8 sections that were completely built from the subgrade up for pavement structure analysis. Strain gauges, pressure plates, and temperature probes were built into the structural sections to monitor how the different thicknesses and mix designs responded to traffic and temperature changes. The third cycle of the track began in 2006. Twenty-two new test sections were built, including fifteen new surface mix experiments, four new structural experiment sections, and three reconstructed structural sections. Twenty-five new test sections (twelve mix performance and thirteen structural) were built for the track's fourth cycle in 2009.

The fifth cycle of the track began in 2012 and included twenty-one new experimental test sections. Several experiments focused on the use of recycled pavement materials, porous friction course (PFC) mixes, and pavement preservation. These test sections were built on the Test Track and the Lee Road 159. The sixth cycle began a partnership with the Minnesota Department of Transportation's MnROAD facility in 2015, to address two national research needs: (1) to validate asphalt mixture cracking tests that are suitable for routine use in mix design and quality assurance (QA) testing, with seven new test sections on the NCAT Test Track and eight rebuilt test sections on MnROAD's main-line test road; (2) to quantify the life-extending benefits of pavement preservation treatments, by expanding the 2012 pavement preservation experiment with an additional 34 preservation sections on U.S. Highway 280 near the Test Track and also northern sections using the same treatments in Minnesota. The seventh (most recent) cycle that began in 2018 was primarily focused on preservation, balanced mix design, cracking tests, and rejuvenators.

2.3 Key Findings of the Overall Study

This section provides a summary of major test track research findings at NCAT that have resulted in improved specifications, as well as more economical mixes and pavement designs. These key findings are organized into six areas: (1) mix design, (2) aggregate characteristics, (3) binder characteristics, (4) structural design and analysis, (5) relationships between laboratory results and field performance, and (6) tire-pavement interaction (NCAT, 2002, 2006, 2009, 2012, 2015, 2018). A summary of the key findings is provided in Table 1.

Table 1 Key findings from NCAT Tracks

Research Area	Sub-area	Key Findings
Mix	Fine- vs. Coarse Gradation	Fine-graded Superpave mixes perform as well as coarse-graded under heavy traffic, which tend to be easier to compact, less prone to segregation, less permeable, and quieter
	Design Gyrations	the N_{design} levels specified in AASHTO R 35 are too high, and many states significantly reduced their N_{design} levels to 50 to 70.
	SMA	SMA maintained better performance while more economical. Smaller NMAS SMA mixtures proved to be rut resistant and durable
	High RAP Mix	Equal or better performance as compared to traditional mixes with moderate RAP contents. No benefit was observed for using polymer-modified virgin binder in the mixes with 20% or 45% RAP.
	Warm-Mix Asphalt (WMA)	WMA could hold up to extremely heavy traffic despite concerns of rutting raised by lab results.
	4.75 mm NMAS Mix	well-designed 4.75 mm mixes are a durable option for thin overlay pavement preservation, with a low cost per mile.
	Balanced Mix Design (BMD)	Validate and assist state DOTs in implementing asphalt mixture cracking tests for balanced mix design and acceptance testing.
	Cold Central Plant Recycling (CCPR)	Test sections performed well with no cracking, minimal rutting, and no appreciable change in ride quality. Using a stabilized base may help control tensile strains and help eliminate bottom-up fatigue cracking.
	Interlayer for Reflective Crack Prevention	Not been as effective as desired on the test sections.
Aggregate	Polishing and Friction	Blends of limestone and crushed gravel provided good performance. high-friction surface treatment using an epoxy binder and calcined bauxite aggregate provided excellent friction.
	Restricted Zone	Mixes with gradations through the restricted zone performed very well and proved that the restricted zone was not necessary and removed.
	Flat and Elongated	Using aggregates with a less strict flat and elongated requirement in OGFC mix improved drainage.
	Aggregate Toughness	Using aggregate with an LA abrasion loss that exceeded their specification limit resulted in more break down but performed very well.
	Alternative Aggregates for HFST	The standard HFST using calcined bauxite aggregate maintained the highest friction and macrotexture. Alternative aggregates did not provide the same level of friction.
Binder	Effect of Binder Grade	A two-grade bump was recommended for heavy traffic projects, validating the benefits of modified binders. The most influential factor in rutting was the

		binder's high-temperature performance grade.
	Binder Modification	Excellent performance was observed in all mixes with modified binders regardless of the modifier type.
	Alternative Binders	Test sections with TLA and Thiopave pellets were structurally sound and proved the engineering viability.
	Asphalt Bound Surfaces	All sections performed well based on the measured friction and macrotexture.
	Binder Modified with GTR	GTR-modified binder provided the same performance as SBS modification.
	Delta S Rejuvenator	After 1.8 million ESALs trafficking, the surface showed slippage cracks possibly due to the lacking of any silo storage. After correction, no slippage failures were observed, with good ride quality and rutting performance, and comparable cracking performance.
Structural Design & Analysis	Asphalt Layer Coefficient	Recommended that the asphalt layer coefficient could be increased from 0.44 to 0.54, which would result in savings of construction costs.
	Perpetual Pavement	The concept of limiting critical strains to eliminate bottom-up fatigue cracking was validated in perpetual pavement design, which was more cost-effective in a life-cycle cost comparison.
	Measured vs. ME Predictions	Pavement ME over-predicted rutting in the range of 70 to 100%. ME fatigue cracking predictions with the default coefficients were also poor for the majority of the sections. Local calibration of the performance models was recommended.
Lab vs. Field Results	Air Voids	Rutting increased significantly when the air voids were less than 2.75% for the neat mix. Other mixes containing modified binders or high recycled asphalt binder ratios held up very well under the extreme traffic with air voids below 2.5%.
	Asphalt Pavement Analyzer (APA)	APA test results and rutting on the Test Track and confirmed the 5.5 mm criterion.
	Hamburg Wheel Tracking	The Hamburg test following AASHTO T 324 at 50°C correlated reasonably well with rutting measurements on the track.
	Flow Number	The recommended testing criteria and traffic level performance thresholds of flow number were adopted in AASHTO TP 79-13
	Lab Testing of Friction and Texture	Excellent correlations were established between the friction results in the lab and the field.
Tire Pavement Interaction	Noise	For lighter vehicles, the porosity of the surface was the dominant factor. For heavier vehicles, the macrotexture and the positive texture has a greater influence.
	OGFC Mixes	OGFC surfaces, OR PFCs, eliminate water spray and provide excellent skid resistance.
	High-Precision Diamond Grinding	Areas where diamond grinding was done had no performance problems.

3 ODOT'S DIRECT INVOLVEMENT WITH NCAT

ODOT has been sponsoring the NCAT Test Track studies since its first inauguration cycle in 2000.

3.1 Cycle I (2000-2002)

The first cycle of testing provided data sets to support the transition from Hveem to Superpave mix designs. Along with nine other sponsoring agencies, Oklahoma was among the first states to support this effort. In this cycle, the two ODOT testing sections were S12 (Hveem section) and S13 (4'' Superpave section). Although no detail was provided in the NCAT report for the ODOT sites, the overall research findings supported that Superpave mix design could achieve comparable or better performance than the Hveem mix design method, which has provided ODOT with the confidence to move to the new Superpave design for statewide implementation.

3.2 Cycle II (2003-2005)

In the second cycle, the two test sections funded by ODOT in the first cycle were left for continued evaluations. The rutting performance for the two original ODOT test sections was excellent, with less than 7mm of the rutting (approximately ¼ inch) after about 19 million ESALs.

3.3 Cycle III (2006-2008)

In cycle 3, ODOT funded construction and testing of two new sections N8 and N9 (Figure 2) using materials similar to what was frequently encountered in Oklahoma. Both sections were fully instrumented to study the perpetual pavement concept and for ME analysis. Section N8 was made up of ten inches of asphalt making a two-inch-thick bottom layer, six inches of Superpave mix, and topped with a two-inch SMA layer. N9 had a total HMA thickness of 14 inches: the bottom layer was three inches thick with an added three-inch Superpave lift. The rich bottom layer (RBL) was a mix designed to 2% air voids instead of 4%. The net result was a 6% design asphalt content within the rich-bottom. Both sections had SMA for the surface mixture and a rich bottom layer (RBL).

Section N9 had asphalt strain gauges and temperature probes to measure thermal and strain gradients with depth. The relationship between strain, temperature, and speed was used to assist the design of perpetual pavements in Oklahoma. The outcome of these studies assisted the validation of M-E pavement analysis and design.

Another objective of ODOT in cycle 3 was to examine the behavior of the two perpetual pavement sections in an accelerated loading environment. Central to this effort was characterizing a field-based threshold for structural design. Section N8, designed using ODOT's traditional pavement thickness design approach, had extensive cracking and considered a failed section at the end of the cycle confirming expectations, while Section N9 may be determined a perpetual pavement based on the beam fatigue performance in the lab, strain measurements on the bottom and cracking measurements on the surface of the pavement.

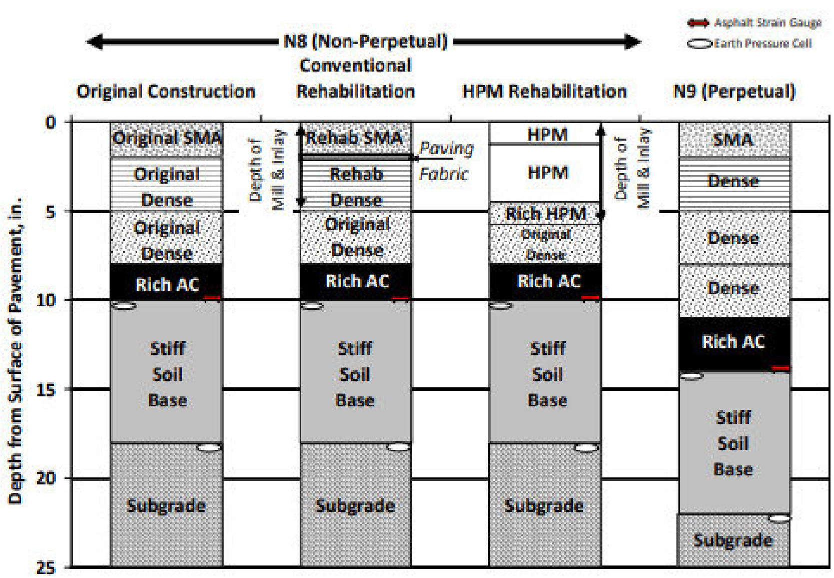

Figure 2 As-Built Pavement Cross Sections for N8 and N9 (NCAT, 2009)