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Benefits Achieved from Florida's Accelerated Pavement Test Program

STATE MATERIALS OFFICE

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EXECUTIVE SUMMARY

The need for faster and more practical evaluation methods under closely simulated in-service conditions prompted the Florida Department of Transportation (FDOT) to initiate an accelerated pavement testing (APT) program in 2000. APT allows monitoring of a pavement system's performance and response to accumulation of damage within a much shorter time period, typically within weeks instead of years. The primary objective of FDOT's APT program is to continuously improve the performance of Florida's pavements. As such, implementation and technology transfer of research findings are of primary importance.

The APT program has become a critical component of FDOT's pavement research program. The success of the program can be attributed to the careful selection of research projects that address vital issues and prolong the life of Florida's roadways. Engineers have successfully used the APT program to gain insight into new pavement technology and design methods that laboratory testing alone could not provide. Most important is the impact the APT program has had on pavement construction and design practices. APT research has led to the revision of FDOT's Flexible Pavement Design Manual and construction specifications and has provided critical information to policy makers. While specific tangible benefits cannot be always directly determined for each project, it is clear that significant savings can be directly attributed to the implementation of APT research. For example, it is estimated that over $4 million is saved each year as a result of APT research and implementation of polymer modified asphalt binders and fine-graded asphalt mixtures.

INTRODUCTION

The evaluation and validation of emerging technologies and innovative concepts require assessing their in-service long term performance. In respect to pavements, the cumulative effects of traffic loading and environmental conditions on the material properties and pavement response are critical in assessing performance and establishing failure modes. The primary disadvantage of such an investigative approach is the extensive time period and expense required to construct and monitor pavement sections over a long-term period.

The need for faster and more practical evaluation methods under closely simulated in-service conditions prompted the Florida Department of Transportation (FDOT) to initiate an accelerated pavement testing (APT) program in 2000. APT is generally defined as a controlled application of a realistic wheel load to a pavement system simulating long-term, in-service loading conditions. APT allows monitoring of a pavement system's performance and response to accumulation of damage within a much shorter time period, typically within weeks instead of years. The primary objective of FDOT's APT program is to continuously improve the performance of Florida's pavements. As such, implementation and technology transfer of research findings are of primary importance.

Over the first twelve years, research findings from the FDOT APT program have resulted in a significant impact on Florida's roadways. Engineers have successfully used the APT program to gain insight into new pavement technology, design methods, and construction practices that laboratory testing alone could not provide. Most important is the direct impact the APT program has had on pavement construction and design practices. APT research has led to the revision of FDOT's Flexible Pavement Design Manual and construction specifications. Furthermore, the FDOT APT program has provided policy makers critical information. This paper provides examples of the economic benefits of FDOT's APT program.

BACKGROUND

FDOT's Accelerated Pavement Testing Program

FDOT's APT program was initiated in 2000. The accelerated loading is performed using a Heavy Vehicle Simulator (HVS), Mark IV model. The APT facility is housed within the State Materials Research Park in Gainesville, Florida. The original test site consisted of eight linear test tracks with each test track measuring 150 feet long and 12 feet wide. Seven of the test tracks were extended an additional 300 feet in 2011 so construction of the test tracks could better reflect field practices. The original FDOT test tracks and HVS are shown in FIGURE 1. The supporting soil layers consist of a 10.5 inch limerock base over a 12 inch mixture of limerock and native A-3 soil (as classified by the AASHTO soil classification system). The asphalt surfaces of these tracks are milled and resurfaced as new experiments are conducted. Two additional 50 foot long test tracks are also enclosed by a sump with an interconnecting channel system so that the simulated water table can be controlled.

The FDOT HVS can apply wheel loads between 7 and 45 kips along a 30 foot test strip. The effective test segment within this span is 20 feet. The remaining five feet, at either end of the test strip allows the HVS wheel to load and unload while accelerating and decelerating. A chain-driven carriage system allows uni- or bi-directional load applications. Wheel wander of up to 30 inches can also be induced and dual or single tires can be used. The HVS can apply up to 24,000 passes per day in the bi-directional mode and 14,000 passes per day in the uni-directional mode. To investigate rutting potential of asphalt mixtures, a temperature control system consisting of insulated panels and radiant heaters are used to maintain a constant test temperature of 50°C (120°F). Two 16 kHz lasers mounted 76 cm (30 in) apart on either side of the load carriage are used to measure the rut profile at pre-determined increments during testing. The FDOT standard loading configuration includes a 9000 pound load in the uni-directional orientation with a 4 inch wander pattern using 1 inch increments (1).

FIGURE 1. HVS and test tracks.

FDOT's Pavement Resurfacing Program

FDOT maintains more than 42,000 lane miles of roadway, of which approximately 96 percent are flexible pavements. According to Section 334.046 of the Florida Statutes, 80 percent of the pavement on the State Highway System (SHS) must meet FDOT performance standards. Annual surveys of the pavement surface condition are conducted to determine the performance of the roadway network in terms of rut depth, extent and severity of cracks, and ride quality. This information is then used to properly allocate resurfacing funds and preserve the SHS. Based on FDOT's pavement management database, a flexible pavement's service life prior to being rated as deficient is 14 years on average. During a typical year, FDOT resurfaces more than 2000 lane miles and more than 3 million tons of hot mix asphalt (HMA) is placed, as indicated in FIGURE 2. Historically, approximately 25 percent of this HMA is placed on roadways that require a Traffic Level D (10 to > 30 million ESALs) or E (≥ 30 million ESALs) asphalt mixture. According to recent data from FDOT's Specifications and Estimates Office, structural HMA costs approximately $125,000 per lane mile of interstate.

FIGURE 3 shows that the number of deficient lane miles has been reduced over the last twelve years even though similar levels of lane miles are resurfaced each year. A combination of factors is believed to be responsible for the improvement in pavement performance. These factors include the introduction of the Superpave design methodology, improved quality control and construction practices, and implementation of successful research studies, particularly from the FDOT APT research program.

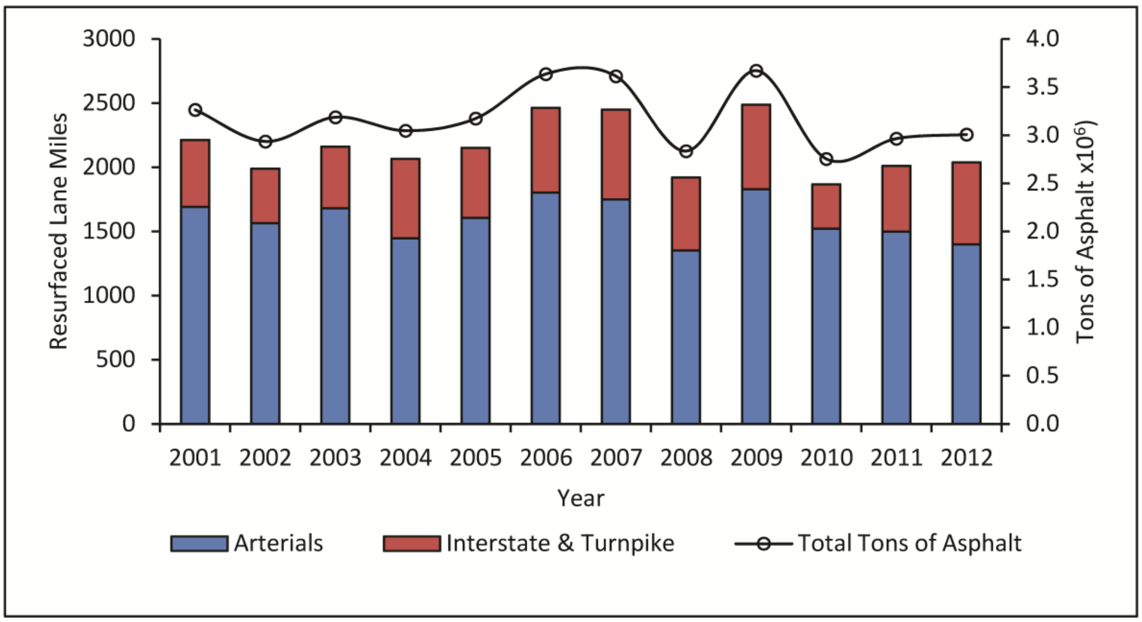

FIGURE 2 Resurfaced lane miles.

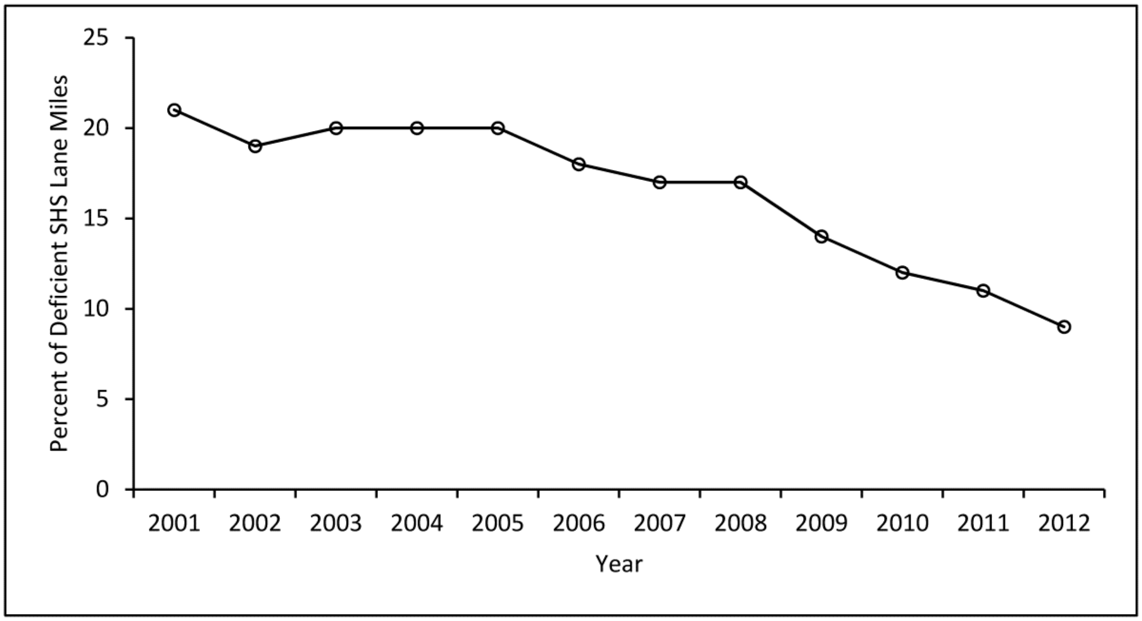

FIGURE 3 Percent deficient lane miles.

SUMMARY AND BENEFITS OF SELECTED APT EXPERIMENTS

The development, planning, and execution of the APT program is conducted on an annual cycle with the support from the FDOT Central and Districts Offices and through partnerships with Florida's University System, industry and the Federal Highway Administration (FHWA). Throughout the year, research needs that address issues affecting Florida's roadways are collected through a well-established process. The process is initiated in the Fall when critical research topics are solicited from all stakeholders. Research needs are classified according to the following three categories:

1. Critical issues that should be addressed by APT
2. Critical issues not applicable to APT but should be performed with in-house resources
3. Critical issues that should be addressed through a contracted effort

Over the twelve years of its existence, the FDOT APT program has investigated flexible, rigid, and composite pavements. Specific aspects that have been studied include the use of polymer modified binder, HMA mixture gradation, damage due to tire types, effect of asphalt rubber membrane interlayers (ARMI), environmental effects (i.e., asphalt aging), early strength gain requirement of concrete for slab replacement and thin concrete overlays. Recently, the HVS has also been used to study a fiber-reinforced polymer bridge deck. Table 1 summarizes the major APT experiments that have been conducted to date. Table 2 summarizes the HMA and concrete materials used for the APT experiments. Additional information is also provided for selected projects in the following sections.

Table 1. Major APT Experiments

Year	Experiment	Findings & Outcomes	Source
2001	Evaluation of polymer modified asphalt binders	Rutting resistance improvement was found even when modified binder was limited to the final structural layer. Revised design manual and specification.	Tia et al. 2002 (2, 3, 4)
2003	Assessment of APT loading	FDOT HVS load parameters were standardized.	Byron et al. 2004 (1)
2004	Early strength requirement of slab replacement concrete	Required flexural strength was defined in terms of slab temp. gradient. A concrete stress/strain prediction model was developed. Verified the maturity method.	Tia et al. 2005 (5)
2004	Coarse & fine graded Superpave evaluation	Fine graded mixtures performed as well as coarse graded mixtures. Revised design manual and specification.	Choubane et al. 2005 (6)
2005	Long-term performance of raised pavement markers	APT was shown to be a practical tool for long-term performance evaluation of raised pavement markers in terms of structural integrity and retroreflectivity.	Choubane et al. 2006 (7)
2006	Thin concrete overlay evaluation	Developed a model for predicting stress/strains for traffic/thermal loads & made design recommendations.	Tia et al. 2007 (8)
2007	Asphalt mixture cracking assessment	Developed and assessed a crack initiation model	Roque et al. 2007 (9)
2008	Evaluation of asphalt strain gauge repeatability	Strain gauges were found to be repeatable when pavement was less than 104°FC (40°F).	Gokhale et al. 2009 (*10*)
2009	Impact of wide-base tires on pavement damage	Wide-base tires were found to perform as well as a standard dual tire. A model to predict pavement response due to tire type was developed.	Greene et al. 2010 (*11*)
2010	Gradation based mixture performance evaluation method	Validated gradation evaluation method to optimize asphalt gradations. Mix design spreadsheet was modified to monitor future gradations.	Greene et al. 2011 (*12*)
2011	ARMI contribution to rutting	An ARMI was found to contribute to instability rutting.	Greene et al. 2012 (*13*)
2011	High polymer modified binder for Increased Rutting Resistance	Rutting and cracking resistance was improved with a high polymer modified binder. This product recommended for use at locations with a history of excessive rutting.	Greene et al. 2012 (*14*)
2013	Ground-tire rubber as a asphalt modifier in structural mixes	Ongoing experiment to evaluate the performance of PG 76-22 rubber modified asphalt binders for use in structural courses.	NA
2013	4.75 mm Mixture as a Preservation Treatment	Ongoing experiment to determine the suitability of a 4.75 mm mixture to be used as a preservation treatment or as an overbuild course.	NA
2013	Feasibility of a Composite Bridge Deck	Ongoing cooperative research project to asses composite bridge decks as a replacement for steel grid decks.	NA
2013	National Study on the Impact of Wide-Base Tires	Research team member for FHWA pooled fund study TPF-5(197).	NA

Table 2. Pavement Structure and Materials

Experiment	Structure	Materials
Evaluation of polymer modified asphalt binders	4 inch SP-12.5 mm	Limestone, SBS modified PG 76-22 binder, & PG 67-22 binder
Assessment of APT loading	4 inch SP-12.5 mm	Limestone, SBS modified PG 76-22 binder , & PG 67-22 binder
Early strength requirement of slab replacement concrete	9-inch plain jointed concrete pavement (12 ft by 16 ft slabs)	Dowels, various cement levels, 900 to1700 psi comp str @ 6 hrs, & 2770 to 4750 psi @ 24 hrs
Coarse & fine graded Superpave evaluation	4 inch fine & coarse SP-12.5 mm	Georgia granite & PG 67-22 binder
Thin concrete overlay evaluation	4, 5 & 6 inch thick bonded concrete overlay (6 ft by 6 ft and 4 ft by 4 ft joints) and 6, 8 & 10 inch thick unbounded concrete overlay (6 ft by 6 ft joints)	Comp. strength of 2400 psi at 24 hrs & 28 day comp. strength of 5800 psi
Cracking assessment of asphalt mixtures	6 inch SP- 12.5 mm	Georgia granite & PG 67-22 binder
Evaluation of asphalt strain gauge repeatability	1.5 inch FC-12.5 mm & 2 inch SP-12.5 mm	Georgia granite & PG 67-22 binder
Impact of wide-base tires on pavement damage	Two 2-inch 12.5 mm lifts & 1/2 inch OGFC	Georgia granite, PG 67-22 binder, asphalt rubber binder (FC-5)
Gradation based mixture performance evaluation	Two 2-inch lifts of SP-12.5 mm	Georgia granite, PG 67-22 binder
ARMI contribution to rutting	SP-12.5 mm overlays of 2 to 4 inches & 1/2 inch ARMI	Georgia granite, PG 67-22 binder, asphalt rubber binder
Evaluation of high polymer modified binder	Two 2-inch lifts of SP-12.5 mm	Georgia granite, PG 67-22, PG 76-22 & PG 82-22 binders
Ground-tire rubber as a asphalt modifier in structural mixes	Two 2-inch lifts of SP-12.5	Georgia granite, various combinations of polymer and rubber modified binders meeting PG 76-22 requirements
4.75 mm HMA mixture as a preservation treatment	0.5 to 1 inch 4.75 mm lift, two 2-inch lifts of SP-12.5	Georgia granite, PG 67-22 and PG 76-22 binder
Feasibility of a fiber reinforced polymer (FRP) bridge deck as an alternative to steel grid decks	4 inch FRP bridge deck	Ultra-high performance FRP

Polymer Modified Versus Unmodified Binders

In 1996, FDOT began using Superpave mixtures for highway pavements. Modified binders were used in some of the Superpave mixtures in an effort to resist cracking and rutting. Since the use of polymer modified binders was a relatively new technology at the time, there was a need to evaluate the long-term performance of these mixtures and the benefits obtained if the use of modified binders were to become standard practice.

The first FDOT APT experiment was designed to address the effects of a styrene butadiene styrene (SBS) polymer modifier on the performance of fine-graded Superpave mixtures (2). This experiment included the following three different pavement structures:

1. Two layers of asphalt mixture with virgin PG 67-22 binder (fully unmodified).
2. One layer of polymer modified mixture over one layer of unmodified PG 67-22 mixture (hybrid).
3. Two layers of asphalt mixture with polymer modified binder (fully modified).

The mixtures contained the same effective binder content, aggregate components, gradation and met all Superpave criteria. The aggregates used for all mixtures were a combination of Florida limestone and local sand. The respective Superpave mixtures were placed in two, 2-inch lifts. Wheel loads were applied using a 425 mm Super-single (Goodyear G286 A SS, 425/65R22.5) tire loaded to 9,000 pounds and inflated to 115 psi. The load was applied in a uni-directional mode with a 4-inch wide wheel wander. The tests were conducted at a controlled temperature of 120°F to represent a typical summer day in Florida.

The average rut profiles for the three pavement structures are shown FIGURE 4. The rate of rutting for the fully unmodified mix was approximately twice that of the fully modified mix. The modified lift placed over the unmodified lift (hybrid) had a slightly greater rate of rutting than the fully unmodified mix, but still performed considerably better than the unmodified mixture. As a result of this experiment, FDOT now specifies that a PG 76-22 binder be used for the top structural lift of traffic level

D mixtures and the top two structural lifts of traffic level E mixtures (*15*). A PG 76-22 binder is also recommended for use at intersections, toll plazas, and areas with a history of significant rutting.

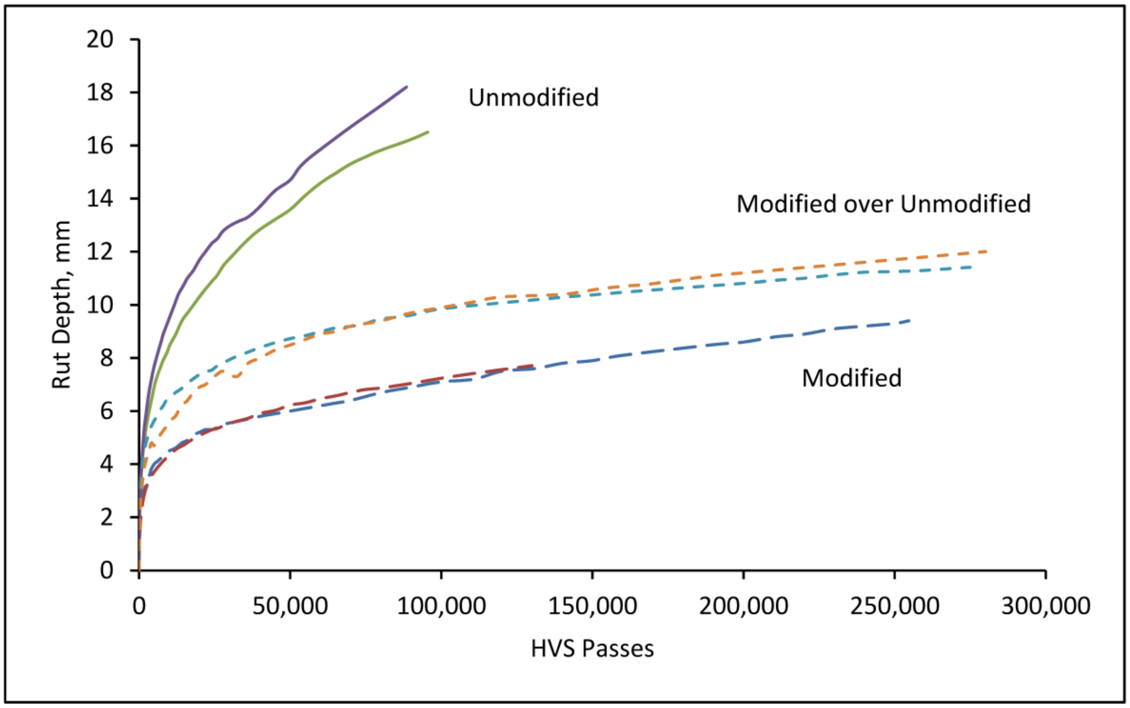

FIGURE 4. Modified binder rut depth profiles.

FDOT has not yet had polymer modified mixtures in place long enough to fully quantify the additional life that can be expected, but others have estimated an additional five to ten years may be possible (*16*). Again, it is also noted that the reduction in the number of deficient lane miles presented in FIGURE 3 indicates that the pavement performance on Florida roadways is improving. As discussed previously, approximately 500 lane miles are resurfaced annually on roadways that require a Traffic Level D or E asphalt mixture. Assuming a modest increase in pavement life of just two years from the use of polymer modified asphalt binder and a typical pavement service life of 14 years, the reduction in annualized cost is just over $1000 per lane mile per year. This corresponds to a cost savings of over $500,000 per year based on recently reported cost of structural HMA and a 3.5 percent discount rate.

Assuming the percentage of Traffic Level D and E mixtures have remained at approximately 25 percent of the paving total, a total savings of approximately $6 million has been realized since the introduction of polymer modified asphalt binders. This total annualized savings is considered conservative since pavement life is likely to be extended for more than two years.

One of the important aspects of the polymer modified asphalt binder research was not only to provide evidence of the effectiveness of polymers to improve pavement performance but also to identify the optimum location to place modified asphalt binders. The APT study showed that good pavement performance was still achievable when modified asphalt binder was used in only the final structural layer. Therefore, the use of polymer modified PG 76-22 asphalt binder is only required in the final structural course for traffic level D mixtures. According to the most recent data from FDOT's Pavement Management Office, polymer modified mixtures cost approximately 11 percent more than unmodified mixes. Each year, approximately 225,000 tons of HMA do not require polymer modified asphalt binder since Traffic Level D mixtures were found to perform well with modified asphalt binder only in the final structural course. Based on this reasoning, an additional savings of more than $2 million is achieved each year. More than $20 million may have been saved since the introduction of polymer modified asphalt binder in 2001, assuming a similar cost difference and percentages of mixture types used throughout the years. Again, this estimate is likely to be conservative since pay items (such as structural asphalt) are not recorded for lump sum contracts which include many larger projects.

Coarse versus Fine-Graded Mixtures

Initial Superpave implementation guidelines recommended the use of coarse-graded mixtures for higher traffic level roadways since coarse-graded mixtures were thought to provide better rutting and cracking resistance. Consequently, FDOT specifications required the use of coarse-graded gradations for traffic level D and E mixtures. In 2004, an APT study evaluated the performance of coarse-graded and fine-graded mixtures (6). Both mixtures consisted of aggregate from the same source and were made with virgin binder, meeting the PG 67-22 requirements. Both mixtures contained the same effective binder content and met all Superpave requirements. The pavement was trafficked with a 425 mm Super Single tire (Goodyear G286 A SS, 425/65R22.5) loaded at 9,000 pounds and inflated to 115 psi. The tests were conducted at a temperature of 120°F. This evaluation showed that the fine-graded mixture performed as well or better despite the commonly held belief that coarse-graded mixtures provided a more robust mix. FIGURE 5 shows the rut profiles of the coarse and fine-graded mixtures.

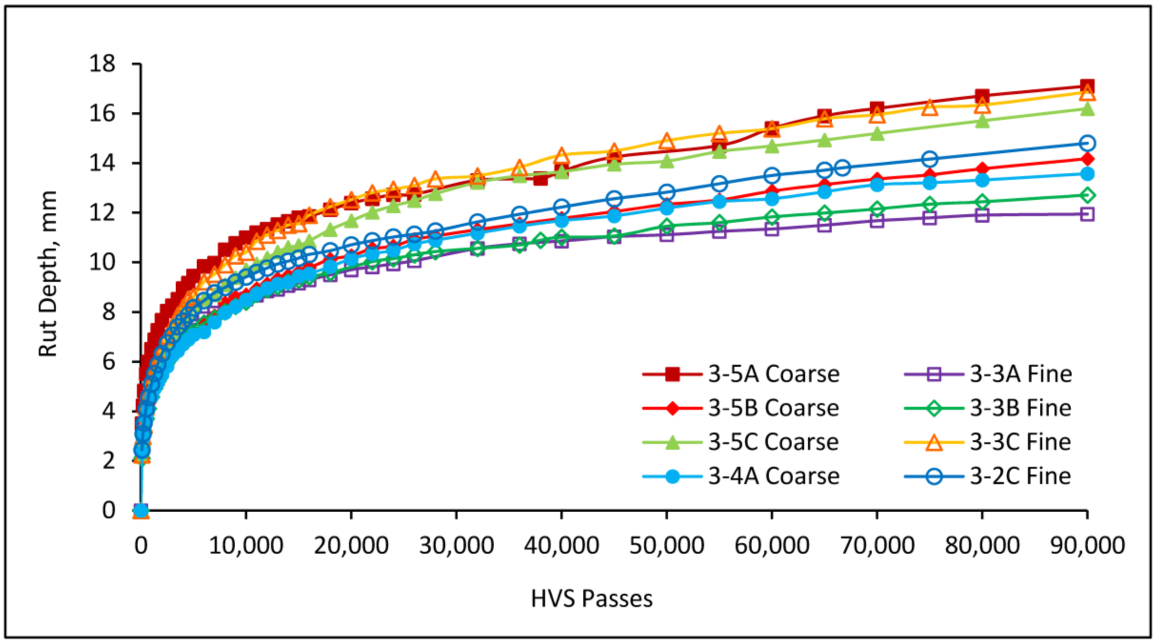

FIGURE 5. Coarse vs. fine-graded rut depth profiles.

In 2005, FDOT revised the Superpave specifications to reflect these APT findings that fine-graded mixtures performed as well or better than coarse-graded mixtures. According to discussions with industry, a cost savings of $2 to $5 per ton of asphalt mix is achieved by using fine-graded mixtures as opposed to coarse-graded mixtures (*17*, *18*). This cost savings comes from reduced time and effort to achieve density and meet volumetric requirements due to improved workability of fine-graded mixtures. Since the noted specification change, contractors have used fine-graded mixtures almost exclusively.

Considering that on average FDOT paves approximately 3 million tons per year and approximately 25 percent of that total consists of traffic level D and E mixtures, an estimated annual cost savings of at least $1.5 million is achieved. It is estimated that more than $10 million have likely been saved since this specification change was made in 2005.

Informed Policy Decision Making

It can be difficult to assess the economic benefits of any research program. Often, it takes years for the actual benefit to be quantified in direct tangible terms. Other times, research may find that current practices are ineffective and should be stopped. Often, the research may be used to support policy decisions or to provide information to policy makers. For example, the trucking industry has claimed economic and environmental benefits due to the use of a new-generation wide-base tire. In 2010, an APT research study showed that the new-generation wide-base tires produce similar or less pavement damage than the standard dual tire (*11*). A 2011 APT study showed that an asphalt rubber membrane interlayer (ARMI), often used to mitigate reflection cracking, was ineffective at reflective crack mitigation and actually contributed to instability and rutting (*13*). FDOT is now sponsoring research to investigate alternative cost-effective reflection cracking mitigation strategies. Also, FDOT is planning on investigating asphalt binders modified with ground tire rubber (GTR) for use in structural courses. The use of GTR modified binder in structural courses may not necessarily result in significant savings. However, if the GTR modified binders are shown to have similar performance as modified binders, the use of GTR could be expanded and potentially reduce the number of landfilled tires and GTR modified binders could create additional alternative (competition) to polymer modified binders and may reduce the overall construction costs.

Educational Benefits

Several APT projects have been conducted in collaboration with Florida state universities. Some of these projects involved contracting directly with universities while others simply involved sharing data for graduate level research projects. Eight Ph.D. dissertations and one Master's thesis have been completed using Florida APT data. Table 3 summarizes these academic research reports.

Table 3. Thesis and Dissertations using FDOT APT Data

Year	Academic Report	Thesis/Dissertation Title	Source
2002	Master's Thesis	Evaluation of Superpave mixtures with and without polymer modification by means of APT	Kim 2002 (*19*)
2005	Ph.D. Dissertation	Analysis and verification of stresses and strains and their relationship in failure in concrete pavements under HVS loading	Kumara 2005 (*20*)
2006	Ph.D. Dissertation	Identification and assessment of the dominant aggregate size range of asphalt mixtures	Kim 2006 (*21*)
2007	Ph.D. Dissertation	Creation of a laboratory testing device to evaluate instability rutting in asphalt pavements	Novak 2007 (*22*)
2007	Ph.D. Dissertation	Evaluation of concrete mixes for slab replacement using the maturity method and APT	Manokhoon 2007 (*23*)
2007	Ph.D. Dissertation	Analysis, testing and verification of the behavior of composite pavements under Florida conditions using a HVS	Tapia 2007 (*24*)
2009	Ph.D. Dissertation	Interstitial component characterization to evaluate asphalt mixture performance	Guarin 2009 (*25*)
2009	Ph.D. Dissertation	Development and evaluation of an HMA fracture mechanics based model to predict top-down cracking in HMA layers	Zou 2009 (*26*)
2009	Ph.D. Dissertation	Effects of truck tire type and tire-pavement interaction on top-down cracking and instability rutting	Wang 2009 (*27*)

CONCLUSIONS

The APT program has become a critical component of FDOT's pavement research program and has provided engineers with insight into new pavement technology, design methods, and construction practices. The success of the program can be attributed to the careful selection of research projects that address critical pavement performance issues and prolong the life of Florida's roadways. Implementation focused research such as FDOT's APT program must continue as governments struggle with budgets for infrastructure investment. While a specific economic benefit cannot be quantified for each project, it is clear that significant savings can be directly attributed to the implementation of APT research projects. It is conservatively estimated that over $4 million is saved in a single year as a result of APT research and implementation of polymer modified asphalt binders and fine-graded asphalt mixtures. More than $35 million has been saved since changes in pavement design practices and construction specifications based on APT findings have been implemented. Going forward, APT research will continue to be used to support policy decisions such as allowing trucks to use new generation wide-base tires and potentially using GTR modified asphalt binder in asphalt structural courses. Ultimately, APT will always be about performance and economics.

REFERENCES

1. Bryon, T., B. Choubane, and M. Tia. Assessing Appropriate Loading Configuration in Accelerated Pavement Testing. Proceedings, *2nd International Conference on Accelerated Pavement Testing*, Minneapolis, MN, 2004.
2. Tia, M., R. Roque, O. Sirin, Kim, & H.J. Kim. Evaluation of Superpave Mixtures With and Without Polymer Modification by Means of Accelerated Pavement Testing. Contract BC-354. Tallahassee, FL: Florida Department of Transportation, 2002.
3. Sirin, O., H.J. Kim, M. Tia, B. Choubane, and T. Byron. Evaluation of Rutting Resistance of Superpave Mixtures With and Without SBS Modification by Means of Accelerated Pavement Testing. Presented at the 82nd Annual Meeting of the Transportation Research Board, Washington D.C., 2003.
4. Gokhale, S., B. Choubane, T. Byron, and M. Tia. Rut Initiation Mechanisms in Asphalt Mixtures as Generated Under Accelerated Pavement Testing. In Transportation Research Record, Journal of the Transportation Research Board, No 1940, National Research Council, Washington D.C., 2005, pp. 136-145.

5. Tia, M., & W. Kumara. Strength Requirement of Concrete for Slab Replacement Using Accelerated Pavement Testing. Contract BC-354. Tallahassee, Florida: Florida Department of Transportation, 2005.
6. Choubane, B., S. Gokhale, G. Sholar, and H. Moseley. Evaluation of Coarse and Fine-Graded Superpave Mixtures Under Accelerated Pavement Testing. In Transportation Research Record, Journal of the Transportation Research Board, No 1974, National Research Council, Washington D.C., 2005, pp. 120-127.
7. Choubane, B., S. Gokhale, and J. Fletcher. Feasibility of Accelerated Pavement Testing to Evaluate Long-Term Performance of Raised Pavement Markers. In Transportation Research Record, Journal of the Transportation Research Board, No 1948, National Research Council, Washington D.C., 2006, pp. 108-113.
8. Tia, M., C.L. Wu, P. Tapia, & W. Kumara. Evaluation of Feasibility of Using Composite Pavements in Florida by Means of HVS Testing. Contract BD-545. Tallahassee, Florida: Florida Department of Transportation, 2007.
9. Roque, R., A Guarin, G. Wang, J. Zou, & H. Mork. Develop Methodologies/Protocols to Assess Cracking Potential of Asphalt Mixtures Using Accelerated Pavement Testing. Contract BD545-49. Tallahassee, Florida: Florida Department of Transportation, 2007.
10. Gokhale, S., T. Byron, S. Iyer, & B. Choubane. Evaluation of pavement Strain Gauge Repeatability: Results from Accelerated Pavement Testing. In *Transportation Research Record, Journal of the Transportation Research Board*, No 2094, National Research Council, Washington D.C., 2009, pp. 30-40.
11. Greene, J., U. Toros, S. Kim, T. Byron, & B. Choubane. Impact of Wide-Base Tires on Pavement Damage. In *Transportation Research Record, Journal of the Transportation Research Board*, No 2155, National Research Council, Washington D.C., 2010, pp. 82-90.

12. Greene, J., S. Kim, & B. Choubane. Accelerated Pavement Testing and Gradation-Based Performance Evaluation Method. In *Transportation Research Record, Journal of the Transportation Research Board*, No 2225, National Research Council, Washington D.C., 2011, pp. 119-127.
13. Greene, J., S. Kim, N. Datre, & B. Choubane. 2012. Effect of a Stress Absorbing Membrane Interlayer on Instability Rutting. CD-ROM. Transportation Research Board of the National Academies, 2012.
14. Greene, J., B. Choubane, & P. Upshaw. Evaluation of a Heavy Polymer Modified Binder through Accelerated Pavement Testing. Proceedings, *4th International Conference on Accelerated Pavement Testing*, Davis, CA, 20012.
15. Flexible Pavement Design Manual. Document No. 625-010-002-g. Florida Department of Transportation, Tallahassee, FL, 2008.
16. Von Quintus, H., J. Mallela, and M. Buncher. Quantification of the Effect of Polymer Modified Asphalt on Flexible Pavement Performance. In *Transportation Research Record, Journal of the Transportation Research Board*, No. 2001, National Research Council, Washington D.C., 2007, pp. 141-154.
17. Warren, J., Executive Director, Asphalt Contractors Association of Florida, Telephone Interview, December 2011.
18. Murphy, K. President, Asphalt Technologies, Inc., Telephone Interview, December 2011.
19. Kim, H.J. Evaluation of Superpave Mixtures With and Without Polymer Modification by Means of Accelerated Pavement Testing. Master's Thesis, University of Florida, 2002.
20. Kumara, W. Analysis and Verification of Stresses and Strains and their Relationship in Failure in Concrete Pavements under HVS Loading. Ph.D. Dissertation, University of Florida, 2005.
21. Kim S. Identification and Assessment of the Dominant Aggregate Size Range of Asphalt Mixture. Ph.D. Dissertation, University of Florida, 2006.

22. Novak, M. Creation of a Laboratory Testing Device to Evaluate Instability Rutting in Asphalt Pavements. Ph.D. Dissertation, University of Florida, 2007.

23. Manokhoon, K. Evaluation of Concrete Mixes for Slab Replacement Using the Maturity Method and Accelerated Pavement Testing. Ph.D. Dissertation, University of Florida, 2007.

24. Gutierrez, P. Analysis, Testing, and Verification of the Behavior of Composite Pavements Under Florida Conditions using a Heavy Vehicle Simulator. Ph.D. Dissertation, University of Florida, 2007.

25. Guarin, A. Interstitial Component Characterization to Evaluate Asphalt Mixture Performance. Ph.D. Dissertation, University of Florida, 2009.

26. Zou, J. Development and Evaluation of an HMA Fracture Mechanics Based Model to Predict Top-Down Cracking in HMA Layers. Ph.D. Dissertation, University of Florida, 2009.

27. Wang, G. Effects of Truck Tire Type and Tire-pavement Interaction on Top-Down Cracking and Instability Rutting, Ph.D. Dissertation, University of Florida, 2009.