GENERATING INFRASTRUCTURE FUNDS THROUGH INNOVATIVE PAVEMENT MANAGEMENT

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ABSTRACT

The American Society of Civil Engineers (ASCE) estimates that there will be a need for $3.6 trillion in infrastructure investment by 2020 (1). A portion of this need can be made available through judicious management of the Nation's pavement systems. The Florida Department of Transportation (FDOT) has made significant progress in meeting this objective by continuously improving the performance of its materials, processes, construction methods and management, and pavement management technology. One notable innovation of this effort has been the adaptation of survival analysis through intensive collection and analysis of longitudinal pavement performance data. The methodology allows the projection of the performance of new materials and technology even before significant evidence of pavement distress is apparent. This approach has been applied to pavement ratings for Open Graded Friction Course (OGFC) and Dense Graded Friction Course (DGFC) mix designs as well as Florida FC-2 subclasses of OGFC and Marshall and Superpave subclasses of DGFC. As a result, by incorporating this knowledge into predictive algorithms FDOT has been able to reallocate approximately $3 billion in nonessential resurfacing funds to other infrastructure needs over the next ten years.

INTRODUCTION

Background

The American Society of Civil Engineers (ASCE) estimates that there will be a need for $3.6 trillion in infrastructure investment by 2020 (1). A portion of this need can be made available through judicious management of the Nation's pavement systems.

The Florida Department of Transportation has a centralized pavement condition survey (PCS) that is performed annually in order to rate the State Highway System's (SHS) condition (2). FDOT has collected PCS data since 1976. The PCS data were collected within each of Florida's seven geographical districts until 1985. After 1985, the PCS program was managed from the centralized State Materials Office. This survey collects data that depicts road defects such as cracking, raveling, patching, rutting, and ride/IRI quality. Additionally, FDOT has maintained its Roadway Characteristic Inventory Data (RCI) data set since 1974. RCI information is collected by the Transportation Statistics Office in cooperation with the geographical district offices and includes roadway materials information along with many other attributes. This historical information allows FDOT to determine the longevity (survival age) of any given pavement section.

Problem Statement

The Florida Department of Transportation has developed a survival analysis tool which is utilized to evaluate the service lives of pavement segments. By analyzing these data, it is possible to characterize the behavior of different materials through different regions of the state. This effort has also shown the ability to compare the performance of different asphalt mix formulations over time thereby quantifying the effects of changes in the mix designs. The asphalt mix types evaluated included OGFC and DGFC as well as subclasses of both. This approach has also led to the ability to detect at an early stage the probable future performance of new materials. This report demonstrates the importance of both a survival analysis tool and accurate data in maintaining longer, higher levels of pavement performance.

SURVIVAL CURVE EXPLANATION

The present condition of Florida's flexible pavement system is determined by analysis of data containing ratings for three separate indices - crack, rut and ride. The ratings for these three types of evaluations are represented on a 0 to 10 scale (2).

The application of survival analysis to the data includes the development of survival analysis curves for each distress type and asphalt formulation. These curves are then compared. The survival data consist of a cohort of data for sections that are tracked from placement until they reach a deficient condition. These data are provided by the annual PCS survey that includes every section in Florida every year.

One case evaluated was the performance of Florida's FC-2 subclass of OGFC. By mapping the distress survival analysis curves next to each other, the most common type of distress failure could be identified. This statewide analysis illustrated in Figure 1 demonstrated that the Crack Rating drops faster and affects more of the system than Ride or Rut. The same trend was evident in Figure 2 for Marshall dense mix designs. Due to these results, subsequent analyses focused on the Crack Rating.

The crack rating is represented by three types of cracks, and is accomplished by a visual estimation of the distresses present within each roadway section. The three crack classes are: hairline cracks less than or equal to 1/8 inch wide; cracks greater than 1/8 inch but less than 1/4 inch; raveling and patching; and cracks greater than 1/4 inch in the longitudinal or transverse direction. These defect types are merged to determine the representation of the section's rating. (A crack rating of 10 indicates new pavement with little distress.) The crack rating alongside two other rating analysis can be found in The FDOT Flexible PCS survey handbook (2). This handbook explains how the three ratings crack, rut and ride are collected and reported.

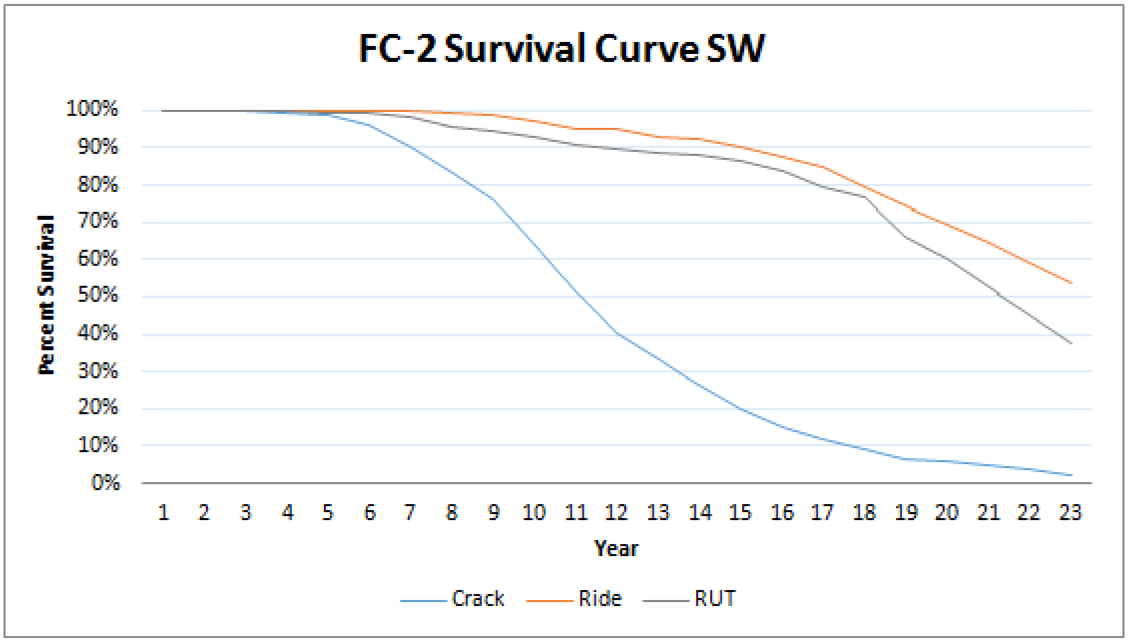

Figure 1. Observed Survival for FC-2 - Crack, Ride and Rut.

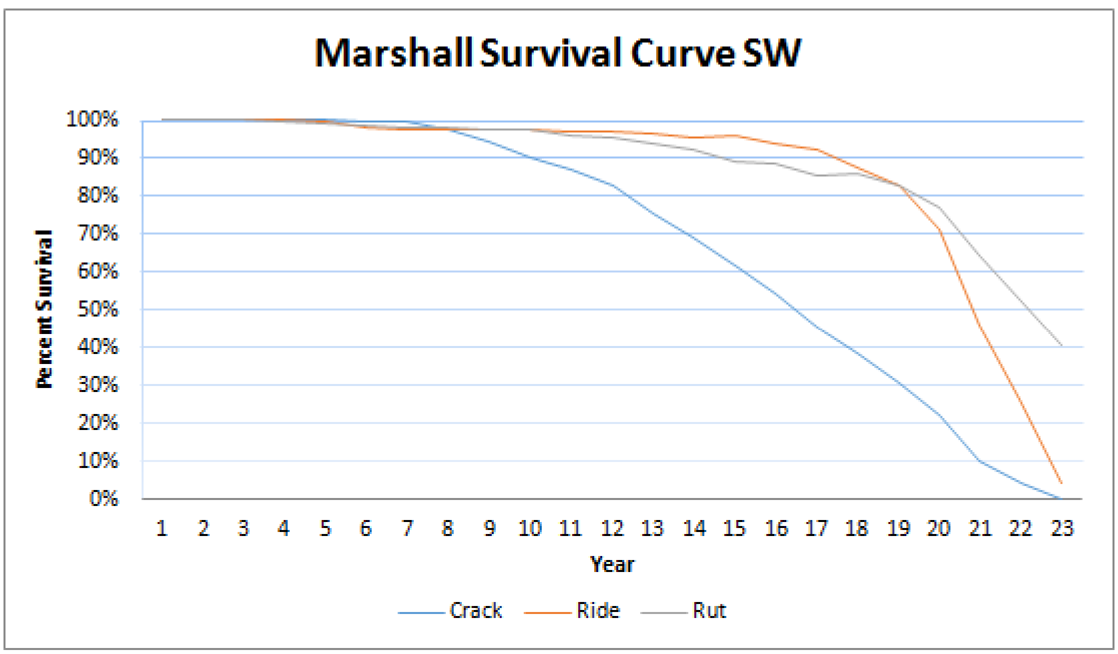

Figure 2. Observed Survival for Marshall – Crack, Ride and Rut.

Normal Survival Curve Performance

The cracking survival curves for both FC-2 class of OGFC mixes and the Marshall class of dense mixes are used to determine an appropriate lifespan for each material. The metric selected for service life of sections is the median survival age. This is the age at which 50% of the sections fall to a deficient condition.

As illustrated in Figure 3 and Figure 4, FC-2 has a survival age of 11 years and Marshall Mix has a survival age of 16.5 years. This statewide analysis demonstrates the significant (and expected) difference in longevity between the open and dense asphalt mixes in Florida.

FC-2 and Marshall mixes were analyzed due to their extensive use in Florida dating back to the late 1970's. Since both mixes have been utilized for three or more decades, a complete life cycle of the PCS data has been collected for many sections. Having a large collection of complete lifecycle data for these materials allows full depiction of normal deterioration curves as a baseline condition to which other formulations can be compared.

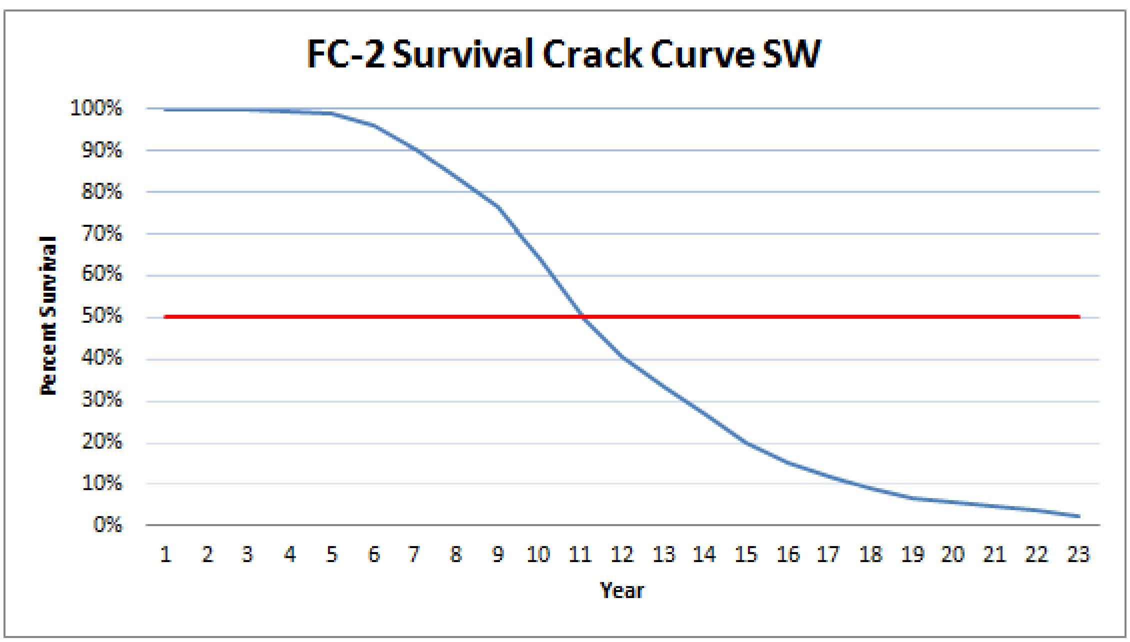

Figure 3. Observed Survival for FC-2

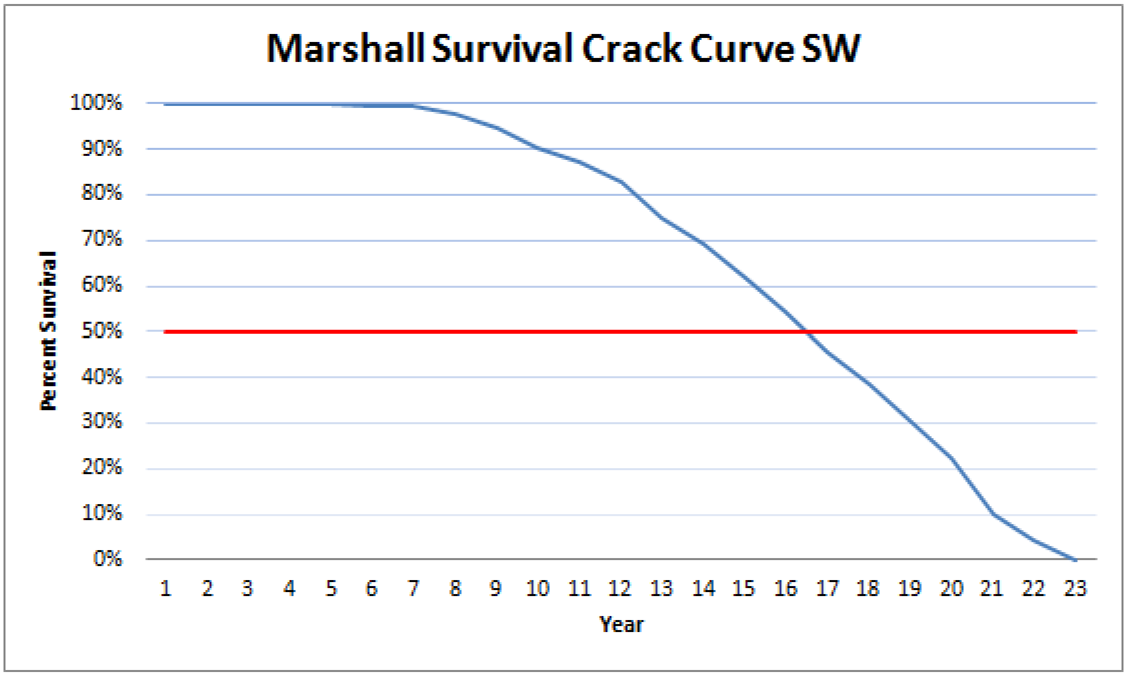

Figure 4. Observed Survival for Marshall Mix

Other more recently selected materials may not have a full life cycle of data collection. These latter types include FC-5 OGFC and Superpave DGFC mix designs. The availability of the full earlier mix design survival curves is useful in estimating the future performance of later designs. Figures 3 and 4 demonstrate the deterioration curves for the State of Florida by FC-2 and Marshall Mix designs.

Implementation Framework for FAST

Due to the importance of not under or over preserving the SHS, Florida uses the Florida Analysis System for Targets (FAST) (3) to forecast the pavement ratings in future years. This allows for a prediction model that directly correlates the work program for resurfacing with pavement section distress ratings. This analysis addresses the reasons that roads have become deficient in past years and allows an understanding of the behavior on a micro level per section. Using the survival analysis results, through the application of several algorithms, the effects of materials on the SHS in terms of the work program can be illustrated.

Survival analysis curves are used to predict how each pavement section in the SHS will behave in the upcoming years. FAST uses the most current ratings to project future conditions based on historical performance for each section and the type of materials used. Survival analysis is used each year to update FAST with the most recent prediction curves.

CURRENT MATERIALS

The current materials present on the SHS are FC-5 and FC-2 (which are OGFC) and Superpave and Marshall Mix (which are DGFC). Analysis of current materials involves comparison of Crack Rating trends among different materials using survival analysis.

Observed Analysis

Materials such as FC-5 and Superpave have only been used statewide since 1998; therefore, a survival analysis performed on these pavements will be inconclusive due to significant number sections that have not completed a full life cycle. In order to evaluate their effectiveness, there is a need to compare them to other known mature materials such as FC-2 and Marshall Mix. Based on the observed survival crack curves, the degree of correlation between the curves for the individual mixes can demonstrate trends between the mixes. A unique approach to service life estimation was necessary because the data for FC-5 and Superpave exist but become sparse beyond ten years. Figure 5 demonstrates that at age ten, FC-5 is surviving 20% longer than FC-2. This is an illustration of how the newer material is surviving in comparison to the known material. When the same process is applied to the Marshall/Superpave pairing illustrated in Figure 6, the apparent difference is 6%. However, both new mix designs are lasting longer than their predecessors. Using this procedure, an earlier stage analysis can demonstrate how a newly introduced material can be expected to affect the SHS.

This earlier stage analysis can illustrates if new materials or processes are actually yielding cost savings associated with increasing service life of the sections. FAST can be utilized effectively using this method as an early detection tool for a cost savings analysis. Without this comparison of different mix data, the state would have to wait until both FC-5 and Superpave have completed a full life cycle for a parallel analysis.

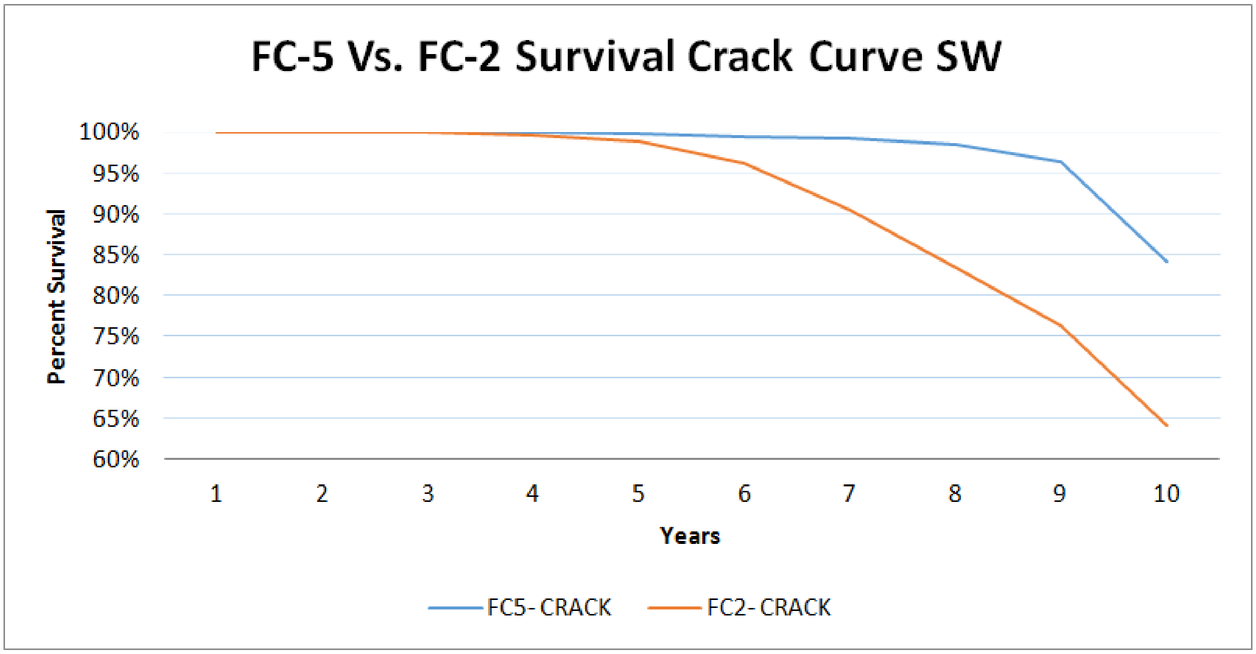

Figure 5. Observed Survival for FC-5 and FC-2.

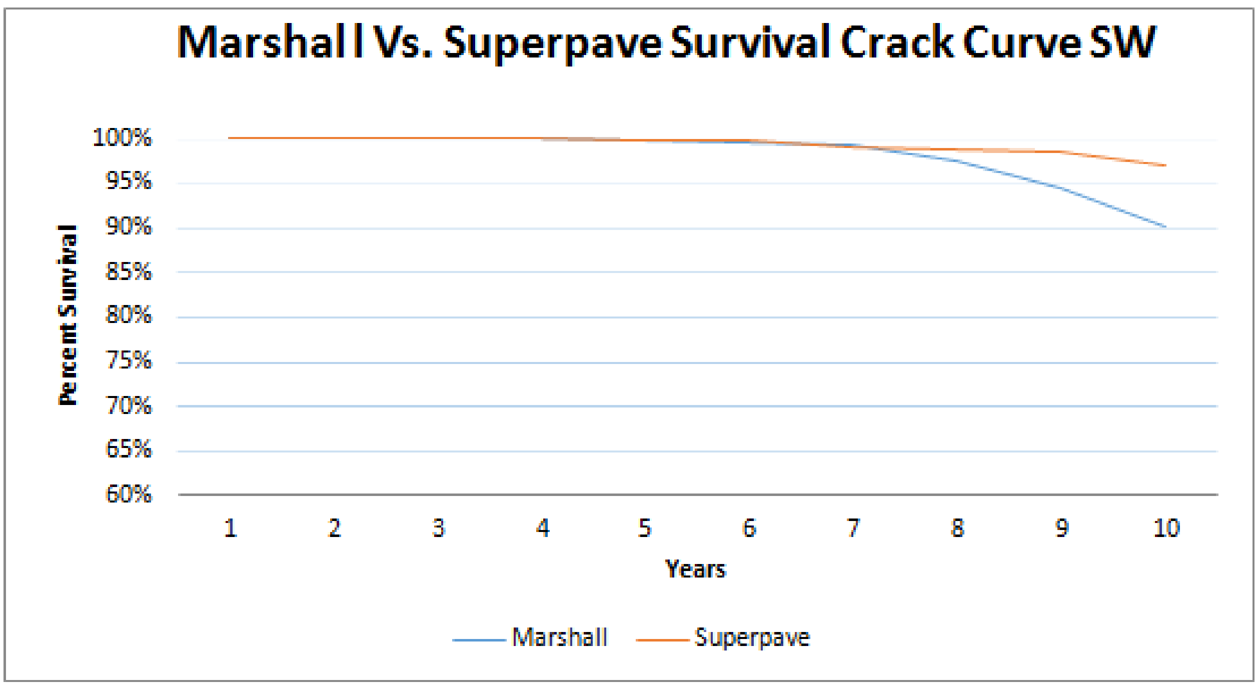

Figure 6. Observed Survival for Marshall and Superpave.

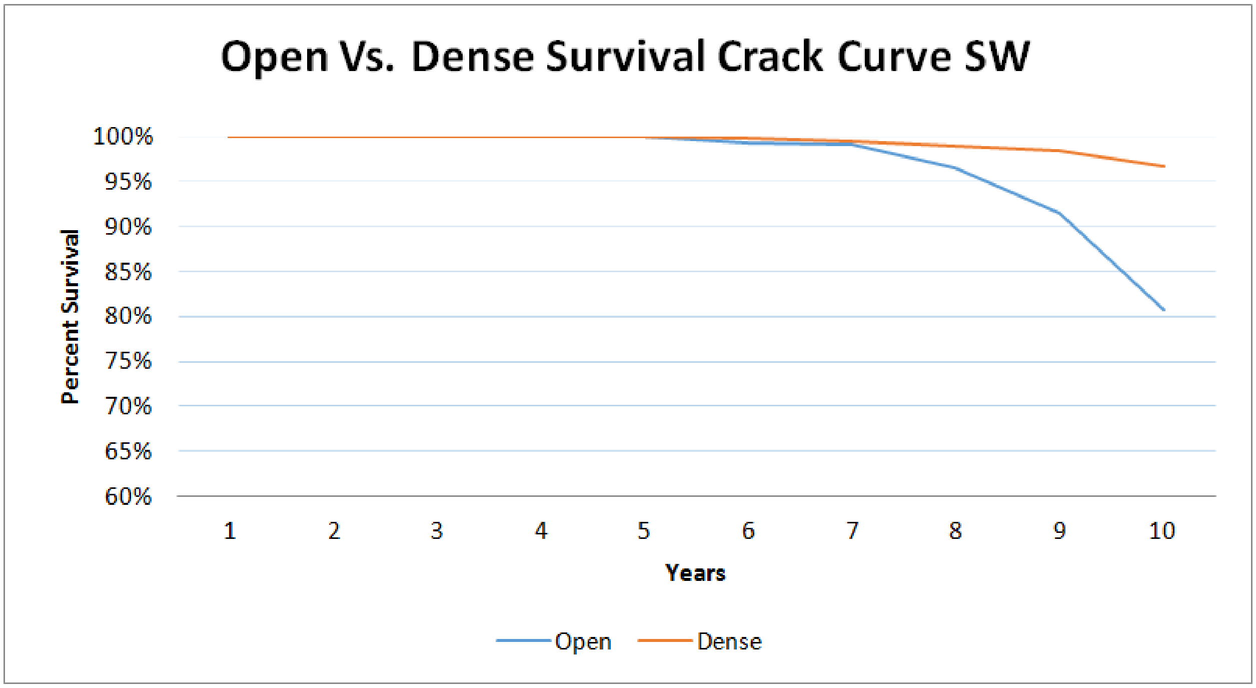

Figure 7. Observed Survival for Open and Dense.

Predicted/Calibrated Forecast

In order to determine the effect that new materials will have on the SHS, a comparison of how the material is behaving relative to a known reference material can be performed. As illustrated in the previous section with Figures 5 through 7, the observed performance can be represented up to the latest available year of data collection. A comparison with a known survival curve for an analogous material can then be made. This is done by offsetting the slope of the predicted forecasted survival percentage with that of the analogous material. In order to demonstrate this analysis, comparisons of both OGFC and DGFC materials were performed.

The known survival curves for the FC-2 OGFC were used with the limited FC-5 data to estimate the future behavior of the newer mix design. This analysis assumes that FC-5 will begin to behave in a manner similar to FC-2. Since the observed life cycle of FC-5 surpasses that of FC-2 at age of ten, it is assumed that this behavior will continue and will eventually follow the pattern of the FC-2 survival curve thereafter. In this way, the offset from the FC-2 curve is continued. This is illustrated in Figure 8 in where the green shaded area represents the offset of the curve between FC-2 and FC-5 for the forecasted years. For this evaluation the 50th survival percentile was achieved for FC-2 at the age of eleven, while the 50th survival percentile for FC-5 is predicted to be the age of fourteen. This process can be used to predict that FC-5 will survive three years longer than FC-2. The difference between these two materials is significant.

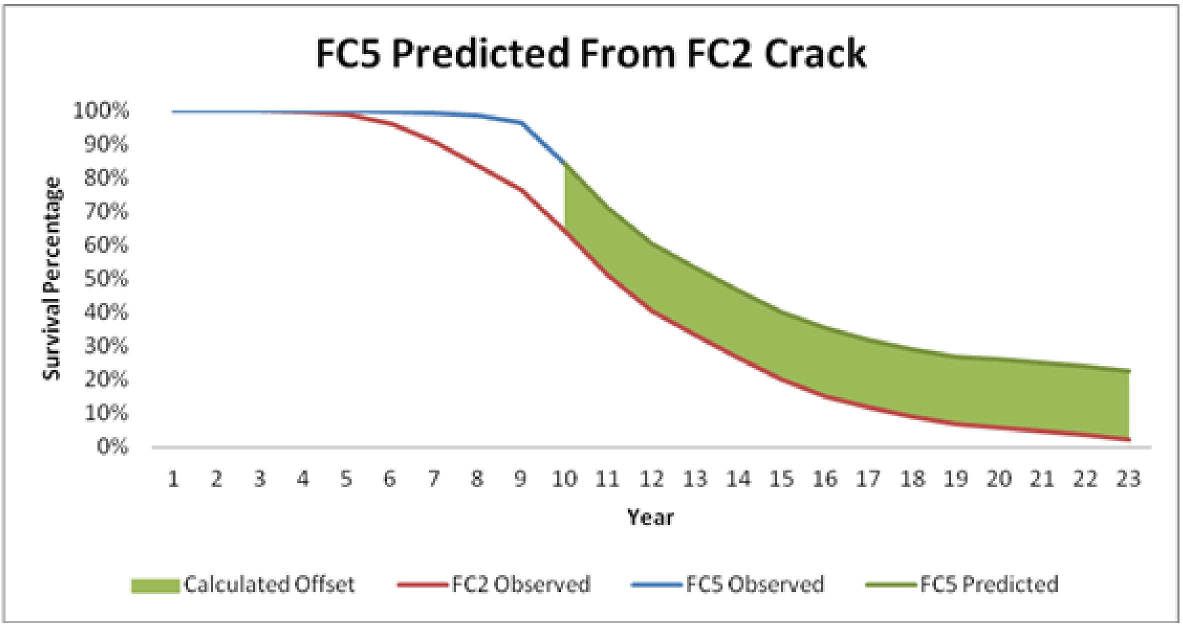

Figure 8. FC-5 versus FC-2.

A similar process was applied to the Marshall and Superpave materials. The result was a difference of 6% as shown In Figure 9. The survival age at the 50th percentile was 16.5 for Marshall and 17.5 for Superpave.

The known survival curves can also be applied to individual sections to generate a forecast of behavior. By using the known relationship for materials used in the SHS, other pavement sections with other mix designs can be evaluated. The question of whether the initial reason for implementation of a new material has positively impacted the section can be answered at an earlier stage than previously possible. This process is useful when the material is designed to survive longer than observed materials in our systems. As illustrated in Figure 8, FC-5 was not a candidate for this offset prediction method until the age of four where it began to show a different pattern than FC-2. The same phenomenon occurs with Superpave in comparison with Marshall mix designs.

During these initial times of uncertainty, it can be assumed that the newly introduced material will behave like the known material.

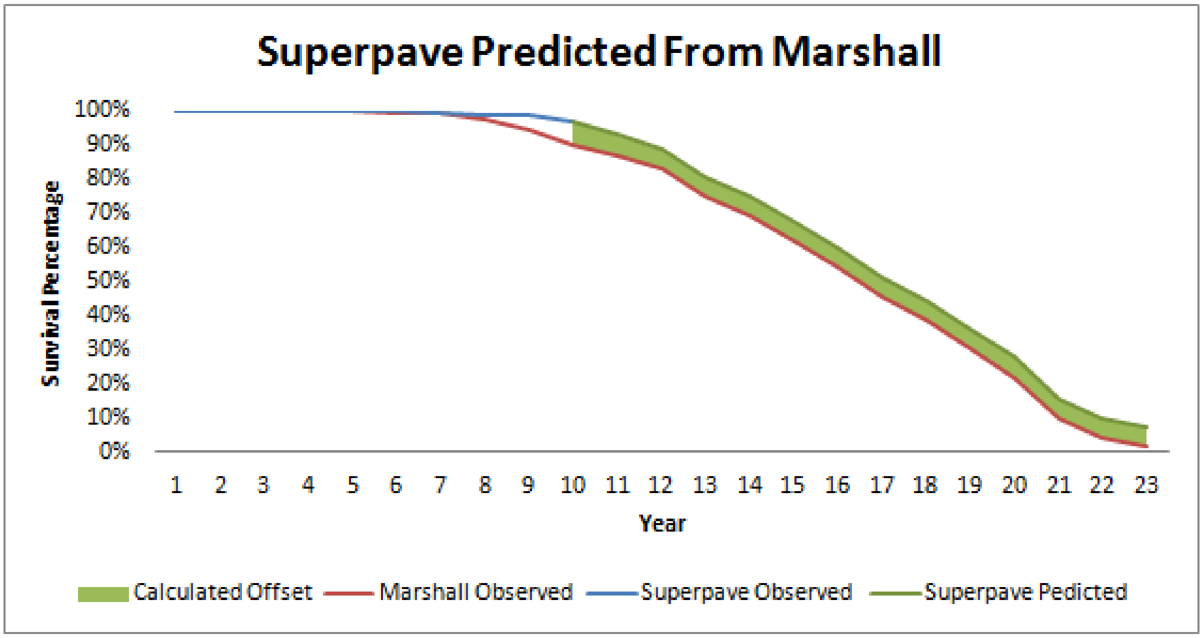

Figure 9. Superpave versus Marshall.

FUTURE MATERIALS

Theoretical predicted survival curves have been developed from known survival profiles in order to estimate the longevity of unknown future materials, mix designs, and methods that may be proposed for the SHS. These reference survival profiles allow assessment of the performance of new materials, etc., at an earlier stage to give the Department an idea if the mix design is behaving as projected. This technique also provides the capability to predict when pavement sections will become deficient.

For example, Figure 10 illustrates the analysis of a future open graded material which underperforms in comparison to FC-2. As shown, after age 5 the material starts to underperform. This event can be extrapolated graphically to predict that the material will not meet the desired 50 percent survival rating after ten years. Depending on why this material was introduced into the SHS, it can be determined whether this particular mix design should be used in the future or discontinued.

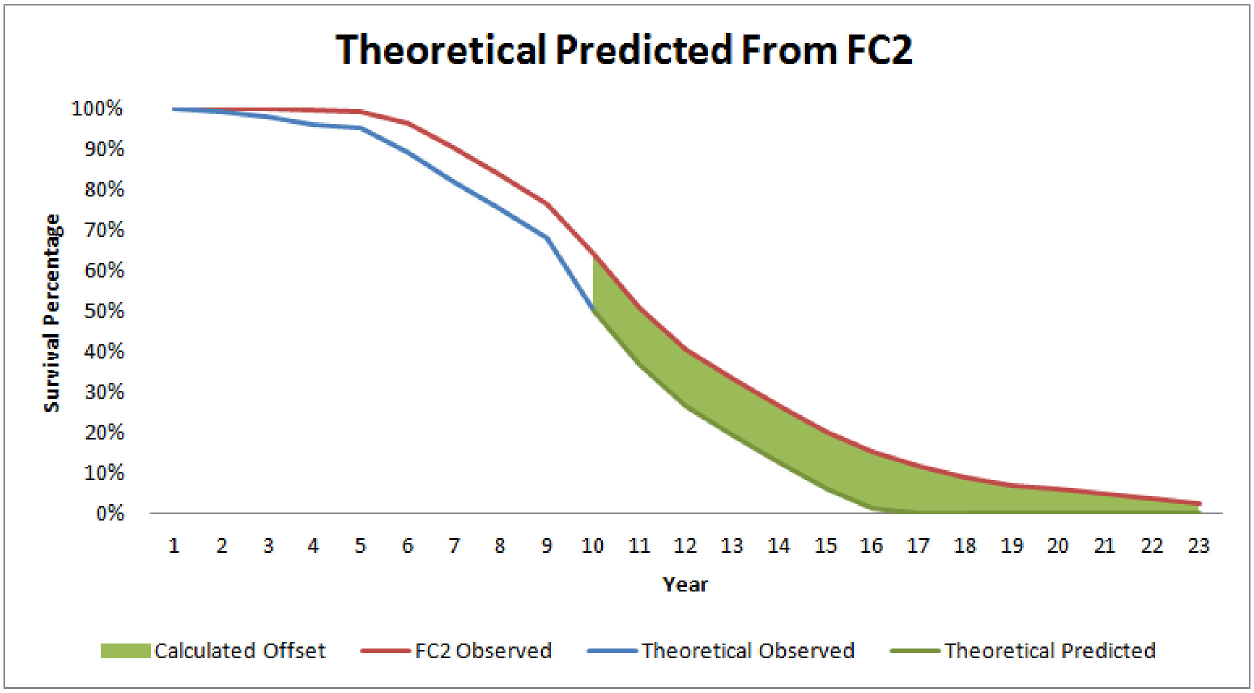

Figure 10. Observed versus predicted performance for theoretical material versus FC-2.

FAST can also be used to predict when sections placed using the future material will most likely fall into deficient condition so that modifications can be made to the work program to provide earlier funding for these years.

An additional example is shown in Figure 11 for another theoretical mix design. In this case, the new mix design is predicted to last longer than the current one. The benefit of analyzing this material at an early stage allows for the determination of the impact of the new material on the Work Program. This may allow for a decision to support the movement of resurfacing funds from the sections predicted to last longer.

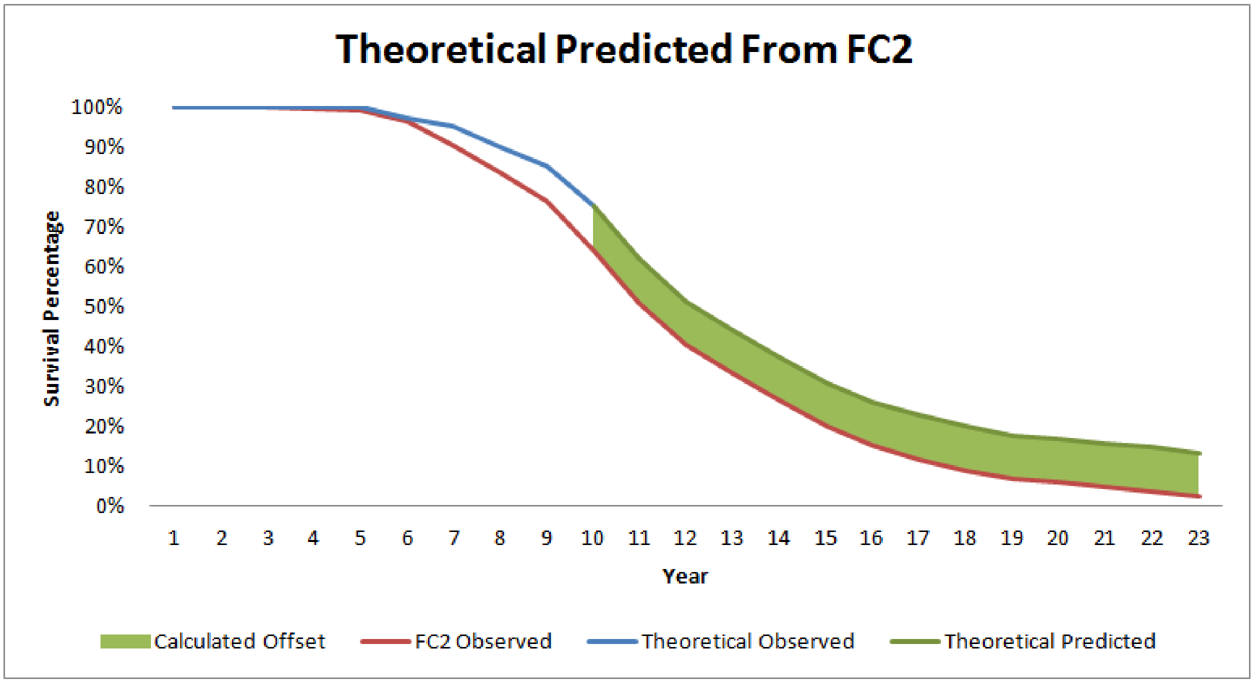

Figure 11. Observed versus predicted performance for theoretical material versus FC-2.

DISTRICT ANALYSIS

FDOT is organized into seven geographical districts. This geographical topology also represents several different environmental zones that generate different meteorological and subsurface conditions that affect the performance of the pavement. Pavements in Districts One, Four, and Six behave significantly differently from those in Districts Two, Three, Five, and Seven due to these conditions.

When generating a survival analysis profile for the SHS, the data for each individual district are analyzed. Because of the different factors affecting each individual district, materials tend to behave differently depending on where and how they are placed. Individual district analysis allows quantification of how each material behaves in comparison to its environmental surroundings.

Once incorporated into the FAST suite of programs, a more detailed analysis of how the section will perform can be developed. This increases accuracy and displays a more realistic representation of the SHS and its behavior.

As illustrated in Figure 12 and 13 for DGFC and OGFC, a different survival age is developed for each based on the material given. For example, DGFC in District Three has a significantly lower survival age than in District Two (see Figure 12). On the other hand, for the OGFC materials, District Six pavements are lasting much longer than District Seven. (See Figure 13). This effect is due to differences in soil, weather, and materials.

Survival analysis supports the forecast generated by FAST in identifying how the overall system will behave, thereby providing the basis for developing the Department's resurfacing program. These analyses yield a better understanding of the evolving condition of the pavement network that allows development of an efficient and effective Work Program. Application of the FAST suite of programs has thereby enabled Florida to reallocate hundreds of millions of dollars annually from resurfacing to capacity projects.

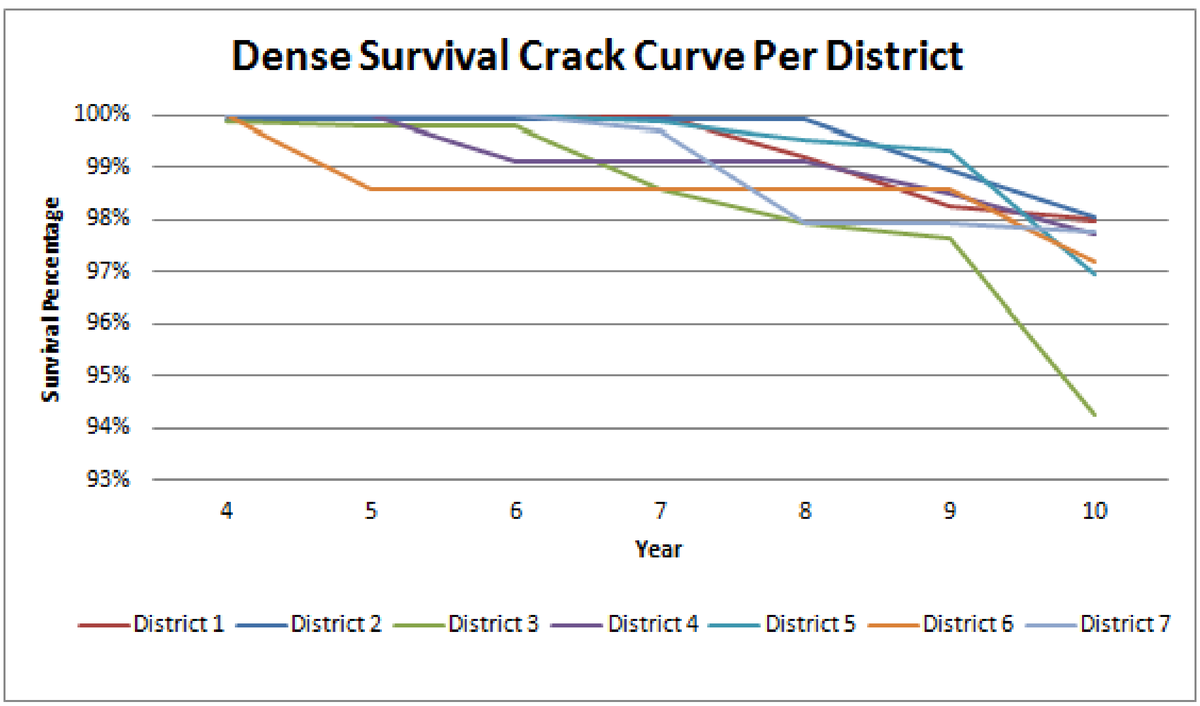

Figure 12. Survival Curve for DGFC by District.

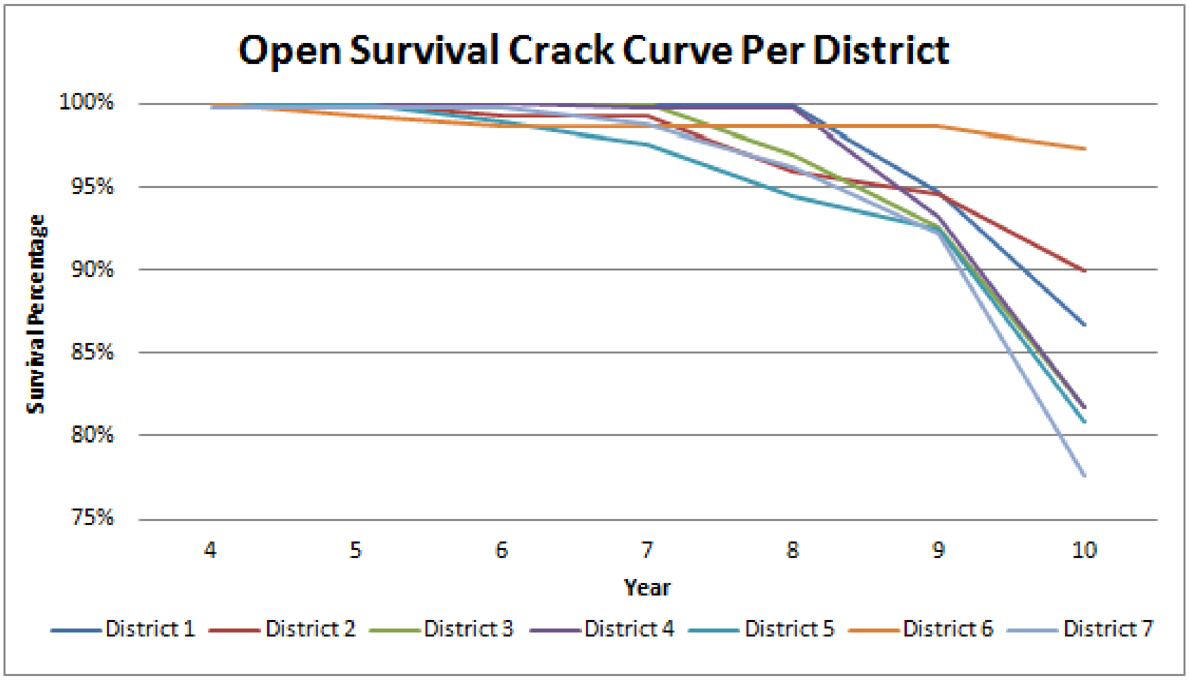

Figure 13. Survival Curve for OGFC by District.

FDOT SAVINGS

As illustrated in Figure 14, the percentage of non-deficient sections has risen from 80.1% in 2005 to 92.7% in 2014. The introduction of new materials, mix designs, and procedures has contributed significantly to increasing the service life pavement sections on the SHS. For this reason, survival analysis has been applied to capture and characterize the ongoing dynamic evolution in the overall performance of Florida's pavements. Through this analysis it became possible to adjust the Work Program to best meet the State's infrastructure needs.

As mentioned, survival analysis is critical to developing the predictive equations included in the FAST suite of pavement management software. These predictive equations are used to forecast the performance of individual pavement sections. These, in turn, are used to predict the performance of pavement sections statewide and in individual districts as shown in Figure 15. The availability of accurate forecasts of pavement conditions allows the Department to judiciously allocate to resurfacing only those funds required to meet the legislated level of maximum deficiency (80%).

The FAST suite of programs and procedures is adaptable to other State Highway Agencies. The data required include distress ratings for a single year, AADT for that same year, percent heavy trucks, type of friction course (open or dense), and the corresponding ages for the sections. Further details about the FAST suite can be found in the paper "Florida's Return on Investment from Pavement Research & Development" (3) to be published in an upcoming Transportation Research Board (TRB) journal.

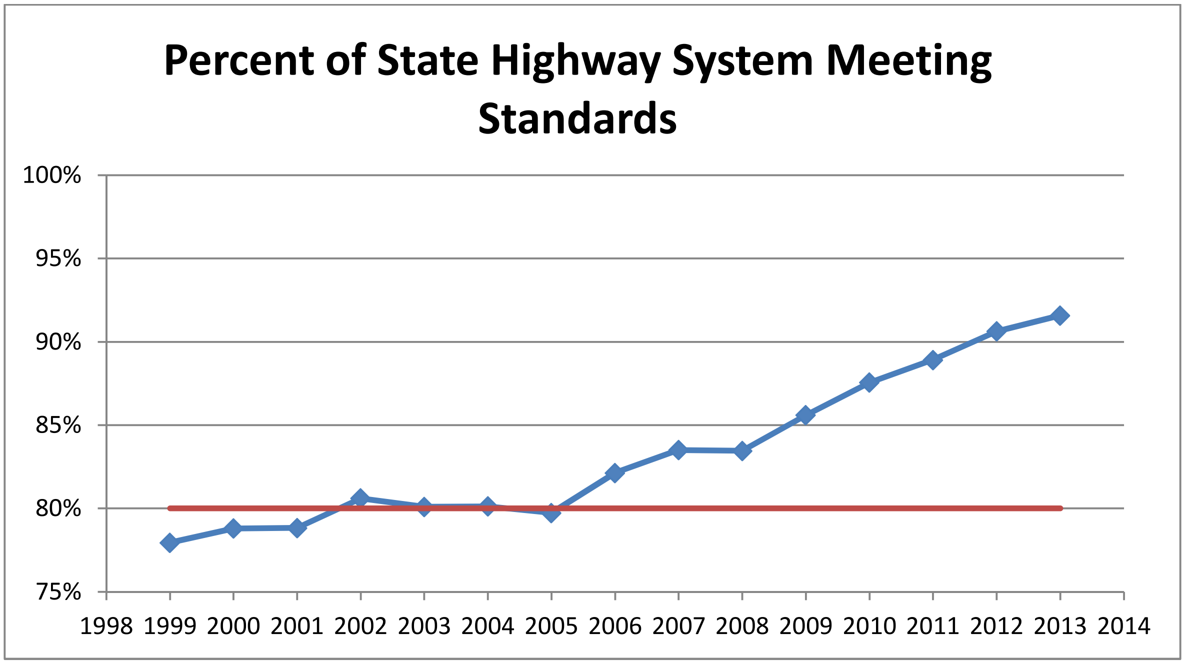

Figure 14. Graph illustrates Percent efficiency for the past 15 years

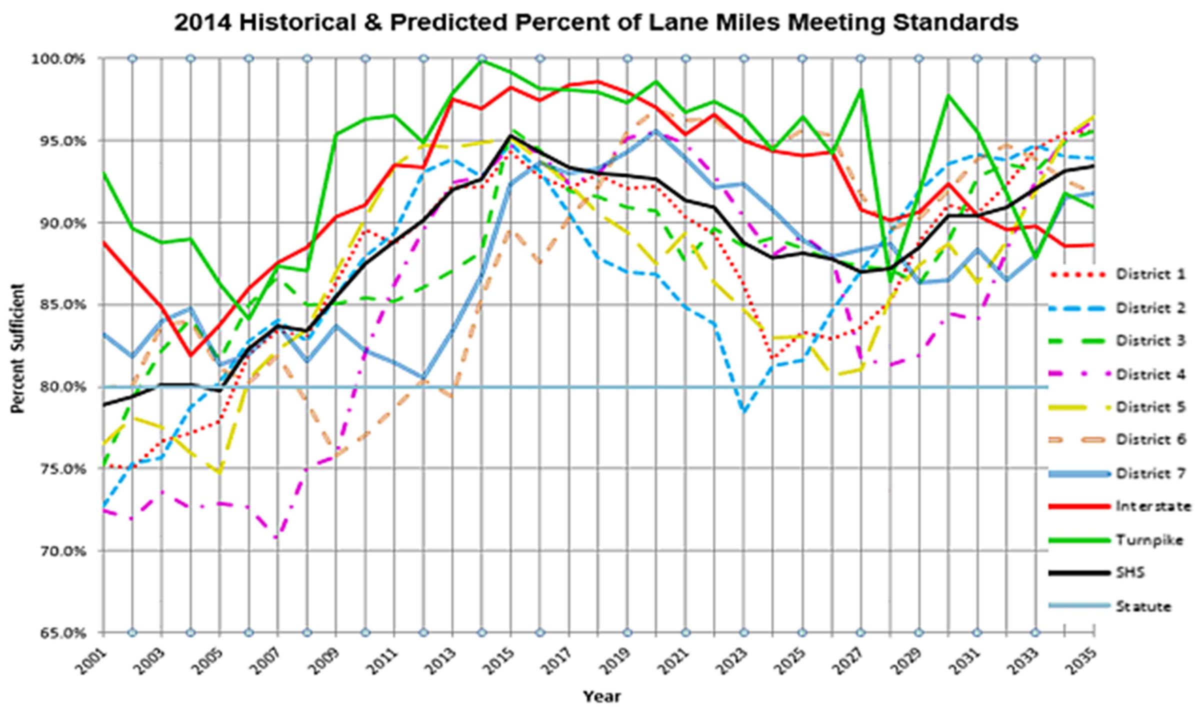

Figure 15. Percent sufficient by District.

SUMMARY

Survival analysis has proven to be an effective tool in learning about the behavioral characteristics of Florida pavements. The insight resulting from the aforementioned analyses has enabled FDOT to assess the effectiveness of different materials, mix designs, and processes. The survival analysis procedure has also allowed the development of predictive models that enable the effective and efficient management of the resurfacing program.

This ability has, in turn, led to the reallocation of approximately $3 billion in nonessential resurfacing funds to other infrastructure needs over the next ten years. Florida had a resurfacing budget of approximately $900 million in 2007 using current year PCS data for project allocation. By using future year estimates, accurately predicted, the annual resurfacing budget was reduced by $300 million per year while maintaining a statewide deficiency percentage of less than 15%, well within the legislated mandate.

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3. Cunagin, WD ,Musselman, J, Taylor, R and B. Dietrich, Florida’s Return on Investment from Pavement Research and Development, in TRB 93rd Annual Meeting Compendium of Papers, No. 01519302, TRB, Transportation Research Board Annual Meeting, Washington, D.C, 2013, pp 19-38.