Impact of Pavement Performance Models on Strategic Funding Analyses in the NCDOT Pavement Management System

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ABSTRACT

In 2012, the Pavement Management Systems Group at the North Carolina Department of Transportation (NCDOT) began a research project with the University of North Carolina at Charlotte to significantly update and improve the pavement distress performance curves used in the optimization module of the Pavement Management System (PMS). The incoming model updates caused the Pavement Management Systems group to begin a major evaluation of the decision trees used in the PMS and how they interacted with the new models. This combination of changes greatly altered the outcome of analysis results and, in general, appears to have led to a more accurate representation of pavement behavior for North Carolina's 80,000 center-line mile (128,747 kilometer) highway network. The paper describes the overall changes in the models and decision trees, the impact to funding of those changes to strategic analysis results and how those impacts were communicated to decision makers.

Introduction

NCDOT manages one of the largest highway networks in the United States. Pavement assets include over 6,000 lane miles (9,656 lane kilometers) of interstate highway, over 35,000 lane miles (56,327 lane kilometers) of US and NC (Primary) routes and more than 121,000 lane miles (194,730 lane kilometers) of secondary roads. The secondary roads include everything from multi-lane, divided highways to subdivision cul-de-sacs less than 0.1 miles (0.16 kilometers) long. The total lane mileage of 163,000 (262,323 lane kilometers) is a challenge to manage in a time period of static or decreasing resources. In addition, the network is still growing as new capital projects are completed and subdivisions outside of municipal jurisdiction are added to the network. The wide variety of route types managed by NCDOT creates a challenging environment in which to manage funding and maximize benefit for the travelling public.

The map of Wake County in Figure 1 illustrates the sheer scope and density of the network. Dark blue lines represent the interstate system, light green US routes, light blue NC routes and yellow the secondary system. Note the clusters of subdivisions. This is common to many counties around the state. Most municipalities manage city streets and subdivisions within their city limits, but there are still many primary and secondary roads threaded through the city systems. NCDOT is responsible for all work on the higher level systems.

Some form of PMS has been in place and maintained by the Pavement Management Unit (PMU) at NCDOT since the early 1980s. For much of that time span, the system was an in-house developed application. The PMS was originally located on a mainframe but was eventually migrated to an enterprise database system with web and client-server interfaces. In reality, this system was primarily a pavement condition tracking system.

Decision trees used the data in the system to recommend treatments for every section surveyed, but no real attempt was made to prioritize treatments or treatment locations. Prioritization was left to the field engineers choosing projects or performed by PMU via spreadsheets and other tools. On a strategic planning level, total instantaneous funding needs were calculated and used as one part of a formula to distribute maintenance, preservation and resurfacing funds to NCDOT's 14 field divisions.

While this system had performed reasonably well for many years, it was clear that in an increasingly uncertain funding environment, a more sophisticated system was needed to modernize pavement management practices. NCDOT was increasingly and appropriately being asked to justify funding levels and a better tool was required.

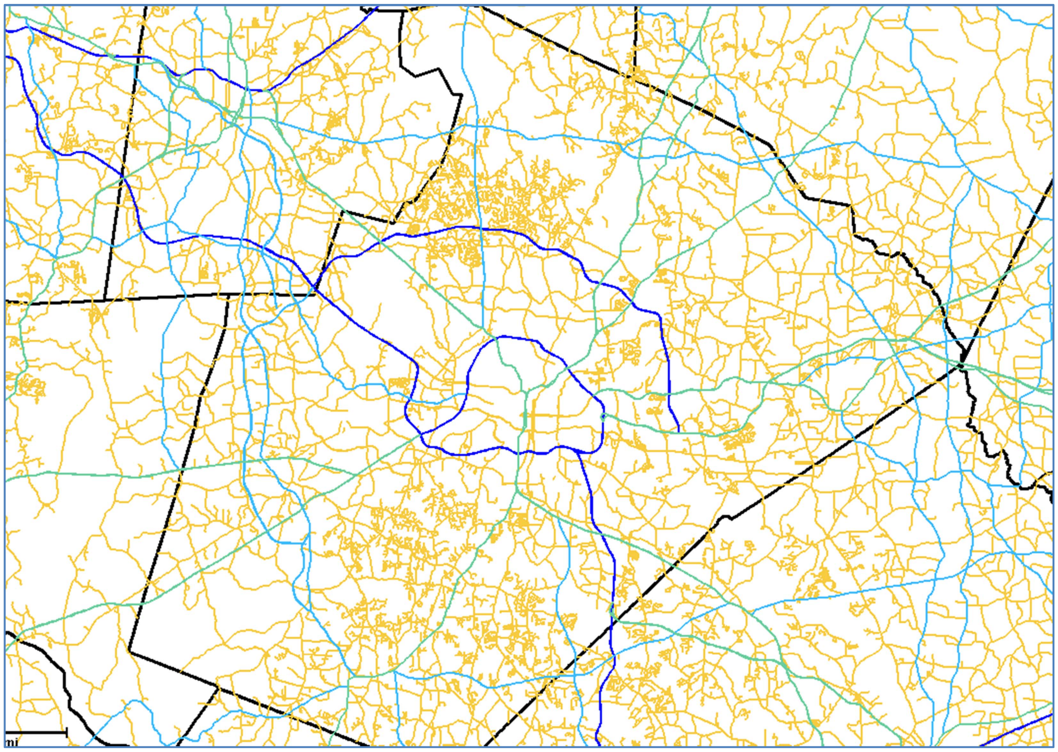
Figure 1 - Example of NCDOT Maintained Highway System

In 2007, PMU implemented a version of the AgileAssets Pavement Manager™ suite. This significantly upgraded the *potential* capabilities of the agency to conduct pavement analyses and improve optimization at both the strategic, "big picture" level and at the local project level. Initial roll-out was as a reporting tool for field users with the analysis capability centralized in the Pavement Management Unit.

Initial Implementation of the New Pavement Management System

As part of the deployment, NCDOT PMU needed to rapidly develop performance models for the new system. While modeling work had previously been conducted, it had been several years since those models had been updated. Due to the sheer size of the highway network, NCDOT has always used family curves for modeling. There is simply no reasonable way to maintain unique section curves. In the span of two months, Pavement Management put together curves broken out by pavement type, Annual Average Daily Traffic (AADT) and system type (Interstate, NC, US and SR).

The primary source of data feeding the old and new PMS was, at the time, bi-annual windshield surveys. Asphalt distresses collected included alligator (Fatigue) cracking, transverse cracking, rutting, raveling, bleeding, oxidation and ride quality. These surveys have been conducted every 2 years since 1982 and for asphalt, covered 100% of the pavement surface. Individual distresses were rolled up into a composite Pavement Condition Rating (PCR). Jointed Concrete Pavement (JCP) surveys were also conducted using a 0.2 mile per mile (320m per 1.6km) sample-based windshield survey.

The AgileAssets system allows for benefit/cost optimization using one model. Typically this model is based on the composite condition score vs age. The areas under the improved and unimproved PCR curves for each section of pavement are compared to find the greatest benefit within the scope of each analysis. Treatments can be triggered by any distress available to the analysis module as long as models and decision trees are defined for that distress. Models were created for the composite score (PCR) as well as for individual asphalt distresses. Due to the number of distresses in the jointed concrete survey, a decision was made to use only the PCR value to trigger treatments.

Often, the biggest issue when building models for pavement distress is poor data quality. Variability is endemic in pavement conditions surveys. Construction records used to determine pavement age are often missing or partial. To minimize the impact when building these early models, a few rules were used when extracting an analysis dataset to screen data that clearly violated performance norms, e.g. very low score but only 1 year old or very high score but 20 years old. In the end, models in the power form were used as it best fit the available data and could be easily analyzed in a spreadsheet.

After model creation, decision trees from the legacy PMS were converted for use in the new system. Adjustments were needed as the new system required an index value of 0-100 for each distress being modeled and used as a trigger. The legacy system triggered treatments directly based on the condition value. For asphalt pavements, collected alligator cracking distress data included severity and extent, while the other distresses were strictly categorical, broken out into “LOW, MODERATE and SEVERE” categories for entire sections.

Need for a Model Update

The new models served well for several years. However, PMU staff members were aware of several critical needs to improve the robustness of the system:

1) A greater number of models were needed to better understand highway network performance. Analysis results suggested there were insufficient families to cover performance variability.

2) A repeatable and defendable method to consistently update models was needed, and this method needed to include extensive data scrubbing.

3) Existing power models were often too aggressive, especially on the secondary system. Slopes on the condition vs age curves were steeper and triggered treatments earlier than would be expected. Essentially, the system aged pavement faster than was realistic on many routes.

Illustrating point 3, historical pavement condition was relatively stable (Figure 2) while analysis using the models suggested a rapid deterioration should be occurring at current funding levels (Figure 3). In general, comparisons across highway systems and geographic areas were acceptable, but if the system was going to be used for project selection and trade-off analysis with other areas (such as bridge funding), more accurate and reasonable models were needed.

Model Research Project

Having identified these needs, the Pavement Management Unit initiated a research project with the University of North Carolina at Charlotte to update our models, indices and benefit weight factors as well as to create a process for future updates.

The end results are already in production at NCDOT and final reports will be forthcoming from the researchers soon. Key pieces of the research project included:

- Intensive data scrubbing algorithms to improve the data feeding model development.
- A more robust method to handle models for categorical data.
- Use of sigmoidal models for continuous data (PCR and alligator cracking), replacing the power form. The extended "tail" of this form more accurately reflects the behavior of end-of-life pavements. Very few pavements ever actually fall to a "0" condition.
- Increased number of model families, including adding subdivision route specific models to address the long life suggested when investigating this data set.
- Chip Seal Models on low volume roads that were more distinct than previous models
- Updating of the index calculation for the Alligator Cracking Index to better associate the calculated index with the raw values and allow better modeling.
- A systematic method to update models as data was updated.

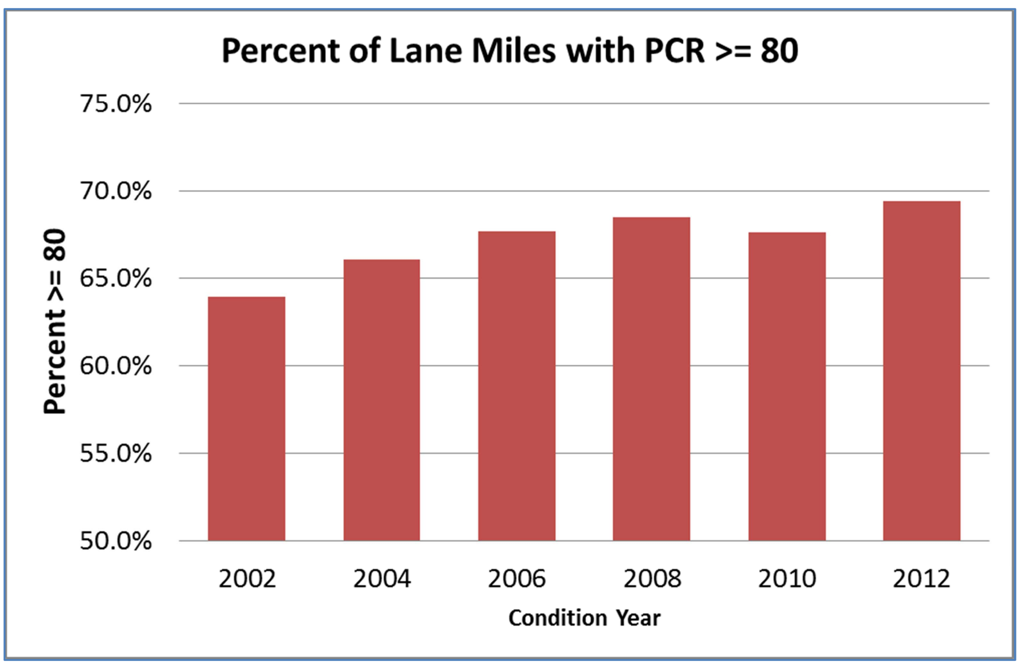

Figure 2 - Overall Pavement Condition Trend

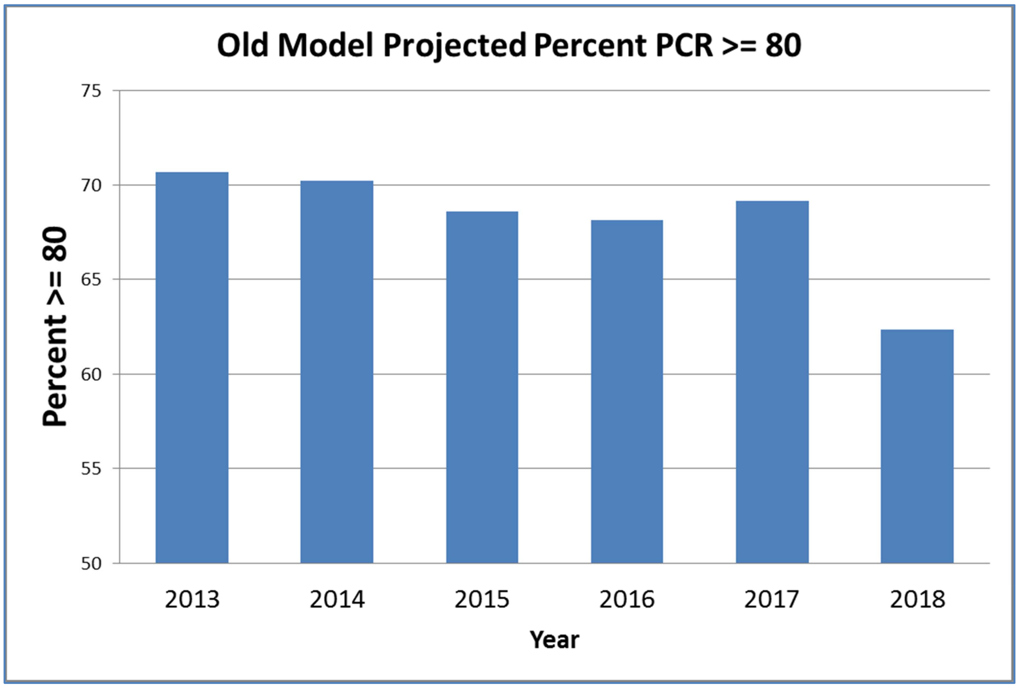

Figure 3 - Projected Overall Condition Using Older Pavement Models and Current Funding Levels

Notes on the New Models

The extensive work on improving model forms triggered several changes in the Pavement Management System. Besides the models themselves, the biggest effort was made in updating decision trees. The new models had a large impact on recommended annual expenditures. This was due largely to less aggressive curves for secondary routes and is discussed below.

Decision Tree Changes

Several modifications were made to the decision trees to address gaps and to improve treatment selection at the correct age for pavements. The main modifications were as follows.

- Creation of a new composite Pavement Condition Rating (PCR) tree
- Adjusting the alligator cracking tree due to the new index calculation
- New decision points based on curb and gutter vs shoulder

PCR Tree

In analyzing results from the optimization runs, it became clear that some roads had an overall condition that should have been treated but were not. No individual distress alone was great enough to trigger a treatment, however, the PCR score was low enough a treatment should have been triggered. This issue led to the creation of a new PCR tree.

The new PCR tree acts as a safety net to trigger treatments for routes that were not being treated based on the existing individual distress trees. A route that exhibits low severity transverse cracking, low severity rutting and a small extent of low severity fatigue cracking would quite likely have been left untreated during analysis as no individual distress would have warranted treatment. When combined, however, those distresses indicate a road in a condition that the traveling public would expect to be treated.

Reconstruction treatments were also removed from the individual distress trees. Previously, only alligator (fatigue) cracking was used to trigger reconstruction for asphalt and chip seal pavements as it is the primary distress for North Carolina pavements. Upon further review, PMU personnel were not comfortable with reconstruction being recommended based on an individual distress and were concerned that truly end-of-life pavements would be missed. Using the PCR tree means that only pavements with the worst level of distress are recommended for reconstruction.

Adjusting the Alligator Cracking Index

The NCDOT PMS uses a maximum allowable extent (MAE) function to calculate the alligator cracking distress index values. Essentially, the areal percentages of low severity alligator cracking, moderate severity alligator cracking and high severity alligator cracking are all passed to a function that converts the values to a 0-100 index. This converts discrete values to continuous numbers and allows the index to be modeled and deteriorated as a single item.

As part of the research project conducted by UNC Charlotte, the extent and threshold values used in the MAE function were evaluated and adjusted so that the new deterioration models fit the data better. The new index also better reflects the performance captured as part of the pavement conditions survey.

The alligator cracking decision tree used index values that were aligned with the old deterioration models and thus were no longer valid. The index decision points of the alligator cracking tree were adjusted by PMU staff to bring the tree into alignment with the new model and MAE values.

Curb and Gutter and Subdivision Routes as Decision Points

As the modeling project progressed, it became apparent that additional decision and model points were needed. Specifically, NCDOT had not previously included break points for curb and gutter routes on any class of road or for subdivision routes on the secondary system. Creating new decision points in the trees allowed for more accurate selection of appropriate treatments.

For example, overlaying a section is typically not an appropriate treatment for a section that has curb and gutter as the gutter could be filled and affect drainage. The appropriate treatment would be to mill and replace, often at greater cost than a simple patch and overlay. Figure 4 illustrates the new curb and gutter decision points in the trees.

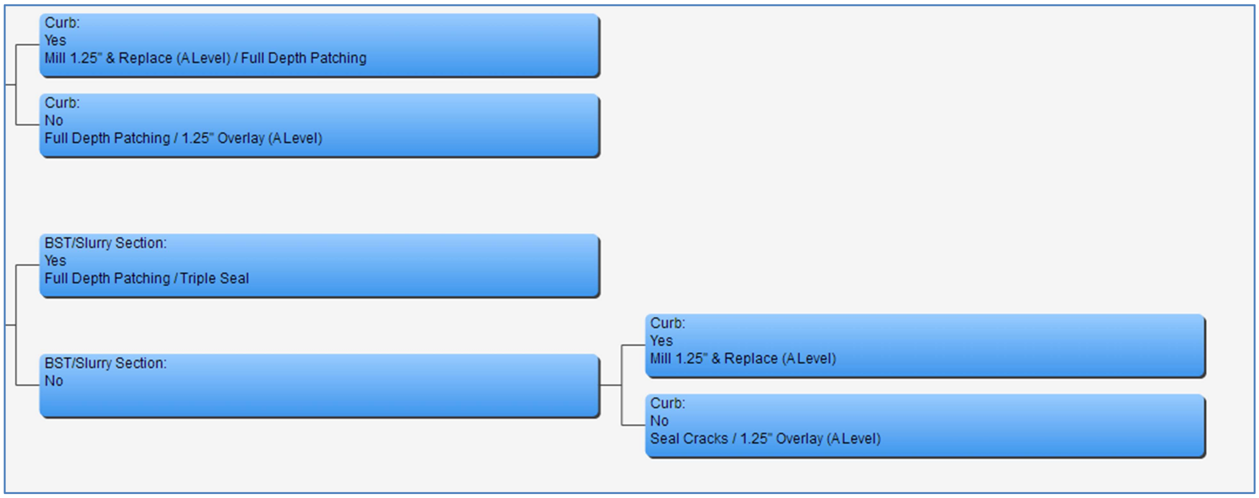

Figure 4 - New Curb and Gutter Decision Points

For subdivision roads, the NCDOT is limited in the types of treatments that can be placed and creating a decision point allowed PMU to limit these treatments. In addition, the modeling project revealed that a decision point was required in the model trees specifically for subdivision roads.

Subdivision Models

Due to typically low traffic volumes, the pavement life of subdivision roads is noticeably longer than other secondary roads. The older, low AADT model is much more aggressive than the new chip seal and plant mix models. Chip seals applied in subdivisions have a life approaching that of plant mix in other applications. Plant mix routes tend to last 3-4 years longer in subdivisions than on other secondary roads.

Figure 5 illustrates the difference between the old low AADT model and the new, separate, models for subdivision chip seals and hot mix asphalt pavements. Green is the chip seal curve and blue is the subdivision curve. Figures 6 and 7 illustrate the issue with graphs pulled from the NCDOT PMS. The large clustering of points on the upper right of Figure 6 demonstrates the huge number of outlying points for subdivision routes using the old models. The new model for plant mix subdivision routes lies much more within the mass of data.

Anecdotally, these graphs also show the need for data scrubbing when building models. Scrubbing is required to achieve reliable condition versus age data for model building.

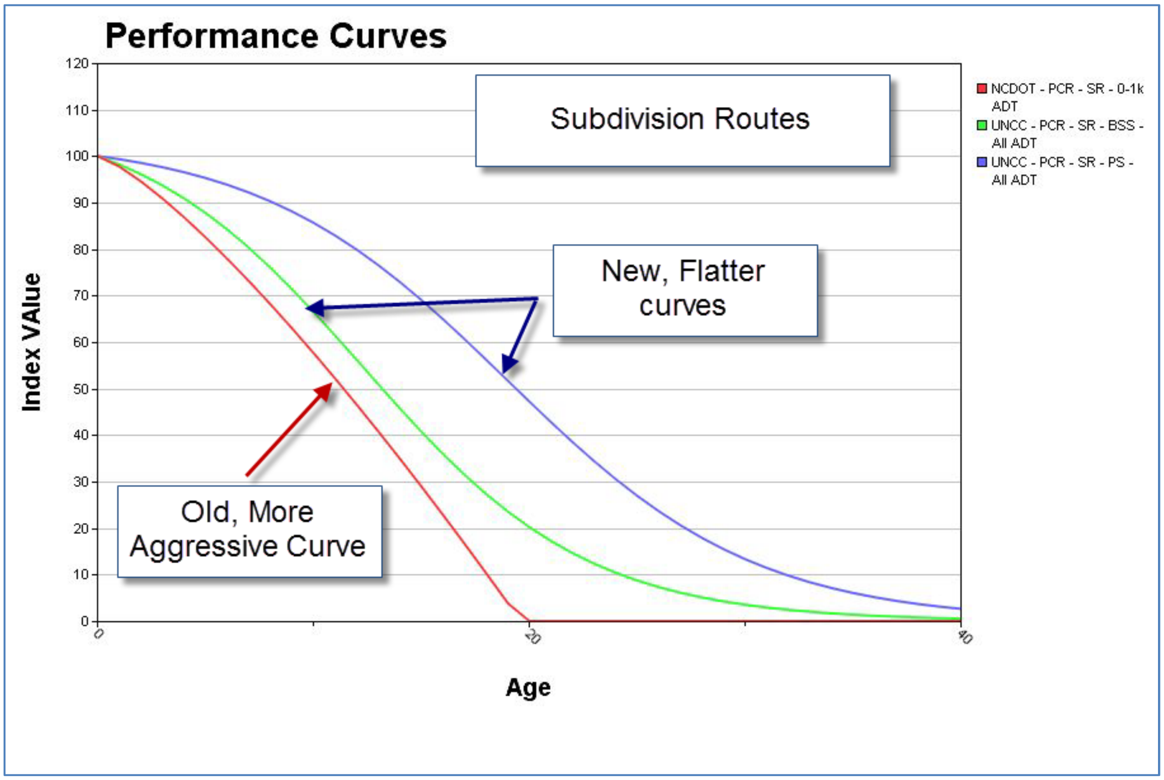

Figure 5 - Subdivision Road Performance Curves

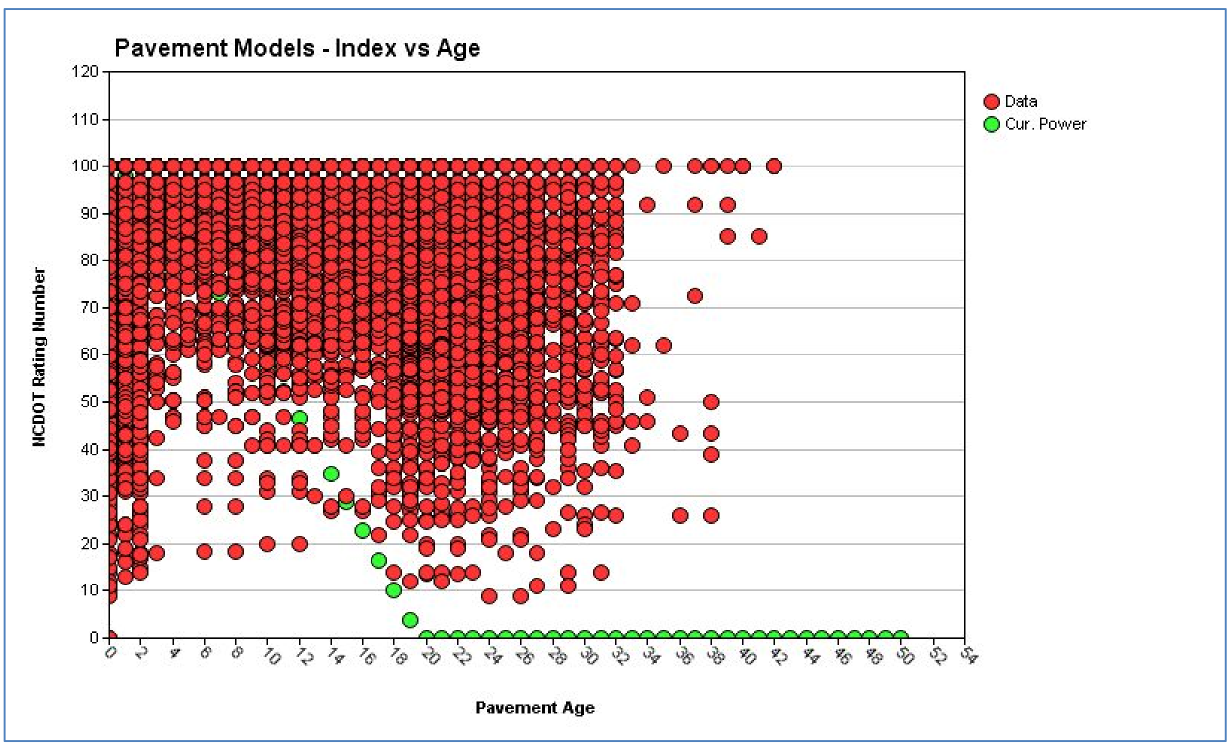

Figure 6 - Plant Mix Subdivision Data vs Old Model

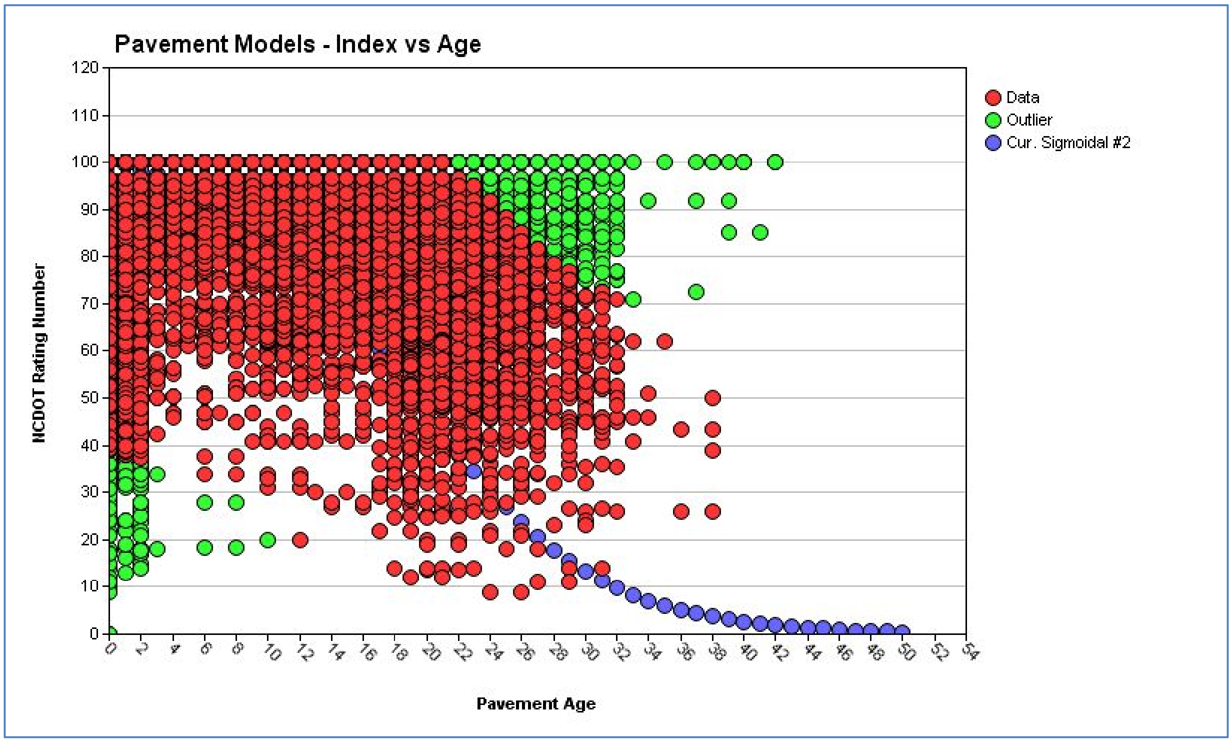

Figure 7 - Plant Mix Subdivision Data vs New Model

Change in Projected Needs

Once implementation of the updates to the deterioration models and decision trees was complete, a large change in funding projections quickly became apparent. Optimization scenarios resulted in significant need reductions based on the results from multi-constraint analysis in the PMS. Using the same dataset, pre-modification analysis indicated a total annualized need of $890,000,000 to meet departmental goals in five years. Analyses run after the new models and decision tree adjustments were made indicated needs reduced by $290,000,000 (**33%**) to $595,000,000.

Change in Need by System			
System	**FY 2014**	**FY 2015**	**Change**
Interstate	$ 135,000,000	$ 80,000,000	$ 55,000,000
Primary	$ 270,000,000	$ 225,000,000	$ 45,000,000
Secondary	$ 485,000,000	$ 290,000,000	$ 195,000,000
Total	**$ 890,000,000**	**$ 595,000,000**	**$ 295,000,000**

Table 1 - Change in Need by System

As can be seen in Table 1, the vast majority of the reduction was made on the Secondary System, effectively redistributing funding towards the primary highway network. As the changes were explored, it quickly became apparent that this occurred for several reasons. First, the old deterioration models were confirmed as too aggressive, and this was especially true for secondary system roads. Figure 8 captures the difference in models on the US network. While the new models are less aggressive (old models in red and green) and have a longer tail, the change is not extraordinary for most of the life of the pavement. Figure 9, however, shows the remarkable change in the performance of non-subdivision secondary roads. This large change is due to improved data scrubbing, better selection of pavement "families" and an increased number of decision points in the models. A clear separation was also made between chip seal pavements and hot mix asphalt pavements.

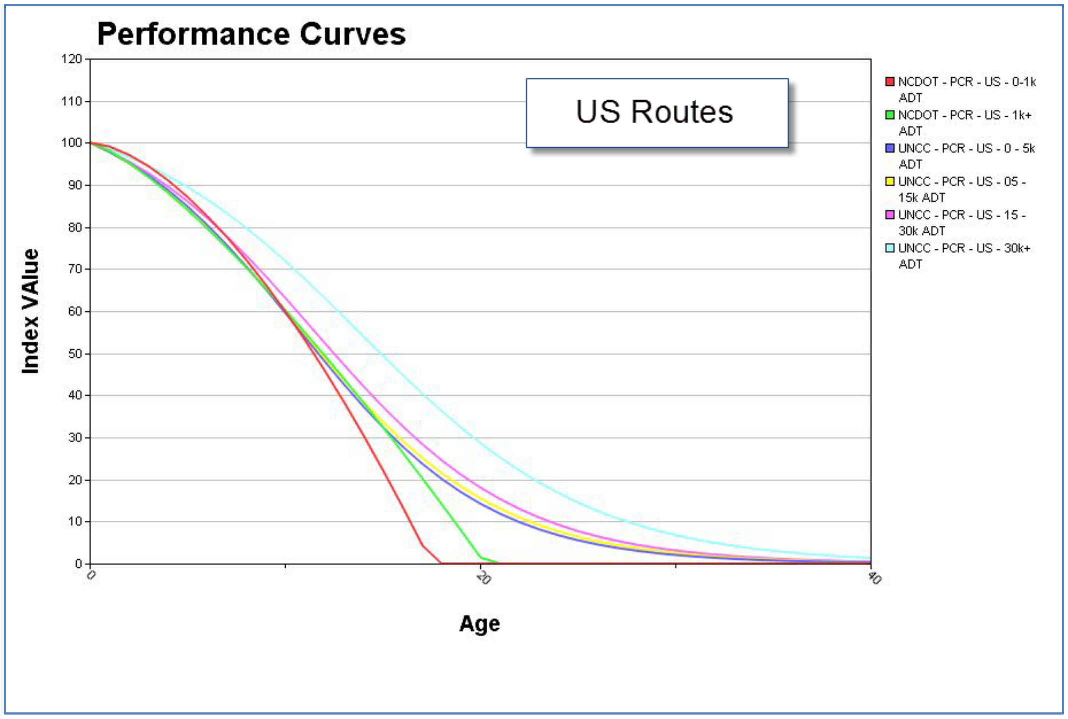

Figure 8 - US Route Performance Curves

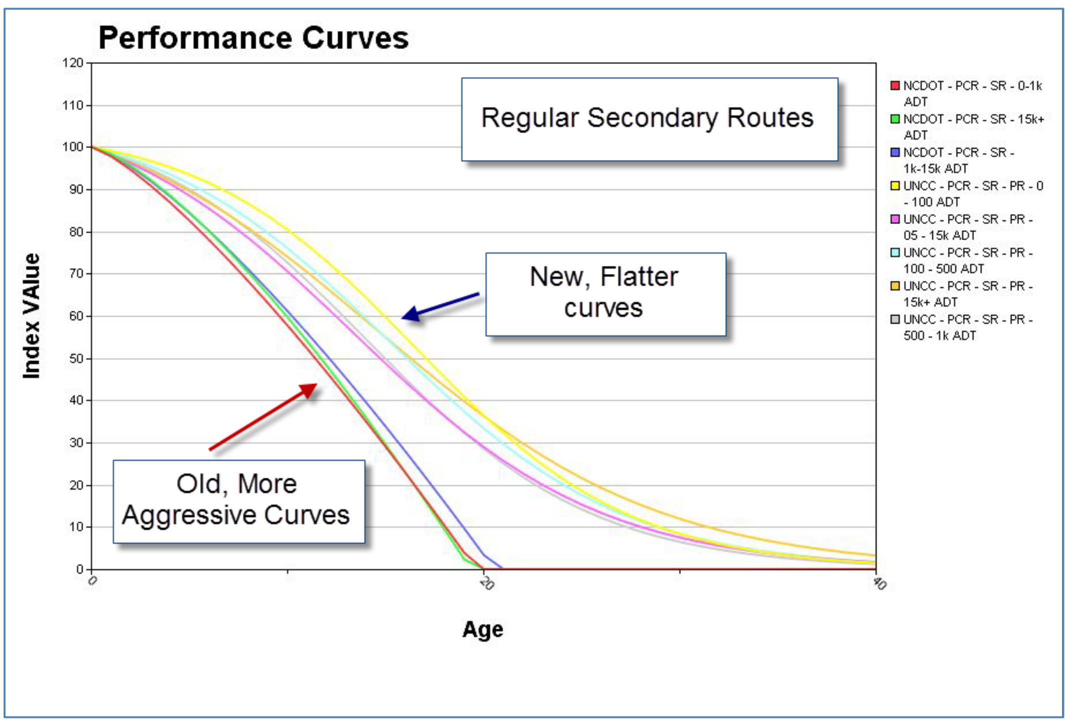

Figure 9 - Secondary Road Hot Mix Asphalt Performance Curves

Looking at the cost estimate reductions from a treatment type standpoint in Table 2, the largest reductions came in reconstruction and resurfacing treatments, $73,000,000 (91% reduction) and $168,000,000 (40% reduction) respectively.

The reduction in reconstruction needs occurred due to moving reconstruction projects to the new, overall PCR tree. The original alligator cracking distress decision trees overstated the need for reconstruction.

The reduction in resurfacing needs is the result of two changes: 1) The creation of new models and decision trees that split subdivision secondary routes out from through and collector secondary routes and 2) The creation of new models that split chip seal secondary routes out from hot mix asphalt routes. The previous models did not accurately model the deterioration of many secondary routes as the models were too aggressive. This led to overstating resurfacing needs.

Change in Need by Treatment Type			
Treatment Type	**FY 2014**	**FY 2015**	**Change**
Reconstruction	$ 80,000,000	$ 7,000,000	$ 73,000,000
Rehabilitation	$ 200,000,000	$ 183,000,000	$ 17,000,000
Resurfacing	$ 418,000,000	$ 250,000,000	$ 168,000,000
Other Preservation	$ 14,000,000	$ 12,000,000	$ 2,000,000
Chip Seal	$ 100,000,000	$ 88,500,000	$ 11,500,000
Interstate Maintenance	$ 70,000,000	$ 54,000,000	$ 16,000,000
Interstate Preservation	$ 8,000,000	$ 500,000	$ 7,500,000
Total	**$ 890,000,000**	**$ 595,000,000**	**$ 295,000,000**

Table 2 - Change in Need by Treatment Type

A substantial reduction in calculated needs was shown after implementing model and decision tree modifications. However, it should be noted that calculated needs to meet departmental condition goals still exceed current funding levels for resurfacing, rehabilitation and preservation programs. The calculated funding needs are much closer to budgeted funding amounts than the original scenarios and help to explain the relative stability of the condition scores over time (As shown in Figure 2).

Upper Management Communication and Buy-in

The changes to analysis results were not accepted at simple face value, but the general feeling was that the changes made were realistic. The Pavement Management Unit executed dozens of scenarios to get at the heart of the major changes. Again and again, the models proved to be reasonable. During the many cycles of analysis, small changes were made in decision trees to account for gaps in treatment and make sure trigger points were appropriate. New treatments were added and old ones removed, but on the whole, the results were consistent. Researchers were asked to confirm some of the models using section data and each time, the model forms were confirmed.

The next, and perhaps most important step, was to communicate the magnitude of the changes and reasons for those changes to upper management. It was imperative that NCDOT executives understood the changes being made, why the changes were being made, and the ultimate results of the changes. Upper management buy-in is critical when changes of this magnitude are made to a system that is used for the creation of work plans for field engineers and also used to calculate the funding needs for departmental funding allocations. This information always up in reports to the General Assembly and confidence is critical. Key management targets were the State Pavement Management Engineer, the State Asset Management Engineer, and the NCDOT Chief Engineer.

Pavement Management System Engineers' communications with management consisted of summary emails and regular meetings to provide updates on the progress of implementation and the results due to this implementation. The basic premise was to run analysis using the old models and decision trees and compare the results to running the same analysis with the new models and decision trees. The results were provided in Excel files and broken down by NCDOT Field Division and System.

To explain why the results of the analysis changed pre and post model update, a one to two page document accompanied each revision of the data. This document contained a brief write up on the specific changes that were made and included charts showing the old deterioration curves compared to the new curves. By plotting the curves, it was made visually clear to management why there was a reduction in funding needs. As shown above, the old curves were much steeper with a shorter life expectancy, particularly on the secondary road system.

The research project was also described in detail to demonstrate the level of effort undertaken to get to this point and that the research methodology was sound. In the end, the changes were accepted and it was understood that analysis results were on firmer footing than at any time in the past.

Conclusions and Future Needs

In the end, the research project to update pavement deterioration models, weight factors and decision trees was immensely successful. The final product has resulted in a Pavement Management System with a more robust ability to model the performance of the NCDOT highway network, project the future conditions and funding needs of that network and most critically, justify those analysis results. Due to the extensive renovation of decision trees, the NCDOT Pavement Management also feels that the system even more closely aligns with the needs of field engineers to use analysis results in work planning.

At the same time, the large change in funding needs and the substantially different distribution of those funds created a need to justify and communicate the reasons for the update. Having a third-party research project, using sophisticated analysis tools has allowed just that.

Finally, NCDOT Pavement Management has made a commitment to revisit models and decision trees on a regular basis as new data enters the system. The impact of the current analysis results can be studied as projects are placed on the roads of North Carolina. NCDOT is moving into an era of automated data collection on the primary and interstate highways, and additional work will be needed to incorporate that information into the Pavement Management System.

References

Chen, Don *"Development and Validation of Pavement Deterioration Models and Analysis Weight Factors for the NCDOT Pavement Management System"*, Draft Final Report for NCDOT Research Project RP 2011-01

List of Tables

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