GEORGIA DOT RESEARCH PROJECT 14-05

FINAL REPORT

STUDY OF GEORGIA'S PAVEMENT DETERIORATION/LIFE AND POTENTIAL RISKS OF DELAYED PAVEMENT RESURFACING AND REHABILITATION

Georgia Department of Transportation

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16. Abstract:

Georgia has continuously been rated as one of the states with the smoothest pavements in the United States because the Georgia Department of Transportation (GDOT) has established a standardized pavement condition evaluation system (PACES) for consistent annual pavement performance monitoring. GDOT also established an active, data-driven annual pavement preservation program that determines pavement preservation methods (i.e., treatment criteria), prioritization of the projects (e.g., rating, AADT, etc.), and allocation of the maintenance and rehabilitation funding, using PACES data. This rich pavement performance data from FY 1986 to FY 2014 is extremely valuable because they reveal the actual pavement performance in Georgia. This project is: 1) to study the actual pavement performance of GDOT's in-service pavements using 28-year of pavement condition evaluation data; 2) to study the pavement resurfacing delay situation; and 3) to study the impact of pavement resurfacing delay with a special focus on the pavement resurfacing effectiveness/life and the increases in construction and user costs. Two types of pavement service interval were studied in this project: "Pavement Resurfacing Interval," which represents the time period between two consecutive resurfacing activities, and "Pavement 70 Interval," which represents the time period to reach a rating of 70 that can be used for a consistent performance comparison. After extensive data screening and processing, a total of 370 resurfacing cycles with high-quality data were selected for analysis. The pavement resurfacing interval and pavement 70 interval is 11.6 and 10.3 years, respectively. Study of selected resurfacing cycles with high traffic volume shows the resurfacing effectiveness (Pavement 70 Interval) decreases more than 10% (1 year) at every 5-point drop of COPACES rating when resurfacing is conducted at a rating less than 70. Results indicate the resurfacing delay has significant negative impact on resurfacing effectiveness. More data, especially projects with different traffic volumes, are needed to study the consequence of delayed resurfacing.

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EXECUTIVE SUMMARY

Georgia has continuously been rated as one of the states with the smoothest pavements in the United States because the Georgia Department of Transportation (GDOT) has established a standardized pavement condition evaluation system (PACES) for consistent annual pavement performance monitoring. GDOT also established an active, data-driven annual pavement preservation program that determines pavement preservation methods (i.e., treatment criteria), prioritization of the projects (e.g., rating, AADT, etc.), and allocation of the maintenance and rehabilitation funding, using PACES data. These programs have provided rich pavement performance data from FY 1986 to FY 2014 that are extremely valuable because they reveal the actual pavement performance in Georgia. This research project had the following objectives: 1) to study the actual pavement performance of GDOT's in-service pavements using GDOT's rich historical pavement condition evaluation data; 2) to study the pavement resurfacing delay situation; and 3) to study the impact of pavement resurfacing delay with a special focus on the pavement resurfacing effectiveness/life and the increases in construction and user costs. Two types of pavement service interval were studied in this project: "Pavement Resurfacing Interval," which represents the time period between two consecutive resurfacing activities, and "Pavement 70 Interval," which represents the time period to reach a rating of 70 that can be used for a consistent performance comparison. A total of 370 resurfacing cycles with high-quality data were selected for analyses. The following are the major findings from this research project:

<u>Findings on Pavement Resurfacing Interval and Pavement 70 Interval</u>:

1) The statistical analysis shows that the average Pavement Resurfacing Interval of the 370 high-quality resurfacing cycles is approximately 11.6 years. The average Pavement Resurfacing Interval varies by district, ranging from 10.3 years (District 6) to 12.2 years (District 5). It is noted that very few high-quality resurfacing cycles (2) are on interstate highways; thus, the findings based on the 370 resurfacing cycles may not represent the behavior on the interstate highways. Nor do the findings are for the critical, high, medium, and low priority routes based on GDOT's new route priority system.

2) Comparison of the pavement performance among different traffic-volume categories

(e.g. high, medium, or low) shows a slight decline in the average Pavement Resurfacing Interval for the low traffic volume category (12 years to 11.2 years). There are no distinct differences because roadways with higher traffic volume have better pavement designs.

3) Study of Pavement Resurfacing Intervals by functional classes shows the Pavement Resurfacing Intervals for rural roads are shorter than urban roads (10.9 years vs. 11.6 years). The Pavement 70 Interval has a similar trend with shorter intervals, 9.6 years for rural roads and 10.6 years for urban roads. GDOT's resurfacing practices in urban/rural areas could play a key role. In addition, the difference in the pavement designs could also play a role.

4) The average Pavement 70 Interval of the 370 resurfacing cycles in this study is approximately 10.7 years; this is 0.9 years shorter than the average Pavement Resurfacing Interval. The average Pavement 70 Interval varies by district, ranging from 9 years (District 7) to 10.8 years (District 5). The shorter life in District 7 could potentially be due to its higher traffic volume.

5) Comparison of the pavement performance among different traffic volume categories (e.g. high, medium, or low) shows an average Pavement 70 Interval of 9.8 -10.7 years. The Pavement 70 Interval shows a slight decline when going from a medium traffic volume to a high traffic volume. This is similar to the trend observed in the Pavement Resurfacing Interval.

Findings on pavement distress characteristics:

6) Study of the distresses on the 370 high-quality resurfacing cycles in this study shows the predominant distresses are load cracking, block cracking, and rutting, which contribute to 46.7%, 35.1%, and 8.6% of the total deduct values, respectively.

7) Block cracking accounts for a higher percentage in the southern region (37.4%-39.1% in Districts 2, 4, and 5) than in the northern region (25.5%-32.0% in Districts 1, 6, and 7). This may be because of the underlying concrete pavement, base type (e.g., soil cement), soil type, etc.

8) The average rutting deduct is 2.9, which corresponds to an average rut depth less than ¼-in. This indicates that rutting is not a major concern for triggering resurfacing after the improvements in pavement materials and structural designs.

9) Preliminary study using selected resurfacing cycles (32) shows load cracking Severity Level 1 is first reported in the first 2-4 years after resurfacing. The extent increases 3% per year in the first 5 years and 5% per year in the next 5-9 years. Load cracking Severity Level 2 is reported around the 6th year, and the extent grows at a slow rate (2% per year). Only a few resurfacing cycles were reported with Severity Level 3.

10) Among the 32 resurfacing cycles, the majority of block cracking is rated at Severity Level 1. It is first reported 2-3 years after resurfacing and continues to grow linearly at a rate of 5% per year. An average of 55% of block cracking Severity Level 1 is reported in the 12th year.

11) The high-quality resurfacing cycles were mapped and categorized by Pavement 70 Interval, and AADT illustrates the capability of GIS to display spatial data, which is more intuitive and informative to decision-makers than non-spatial data. With more high-quality resurfacing cycles available in the future, more in-depth spatial analysis can be performed to analyze pavement performance and corresponding geospatial parameters.

Findings on pavement resurfacing delay condition:

12) The average RBR of the 370 high-quality resurfacing cycles is approximately 64.8. Historically, approximately 51% of resurfacing cycles have been delayed for more than one year. Among them, 7% were treated at a rating less than 55. District 4 has the highest RBR, which might imply that District 4 has a more timely resurfacing practice than other districts.

13) The analysis of composite rating shows a consistent and rapid decline since FY2002. The composite rating dropped from 88.4 in FY2002 to 79.8 in FY 2014 and has not been able to meet the network performance goal of 85 since FY 2007. Not only did the resurfacing delay (i.e., pavement with a rating less than 70) increase significantly from 18% in 2010 to 25% in 2014, but also there is an increase in the projects in bad

condition (e.g., a rating less than 55), which may require more expensive treatment. Adequate funding and proper programming are needed for achieving the performance goal (i.e., a composite rating of 85) at the network level.

14) In 2014, approximately 24% (approximately 4,691 surveyed miles) of pavements had a rating less than 70, which were due or past due for resurfacing. These included 139 surveyed miles on interstate highways and 4,552 on non-interstate highways. Districts 6 and 7 have the largest resurfacing delay of 64 and 50 surveyed miles on interstates; District 4 has the largest resurfacing delay of 1,174 surveyed miles on non-interstate highways.

Findings on consequences of delayed resurfacing:

15) Study of pavement RBR and Pavement 70 Interval shows a slight decrease in the pavement life as the RBR decreases (i.e., 0.2 years per point). However, with a small R^2 (0.2) and widespread variations in pavement lives, this relationship cannot be proved to be statistically significant.

16) Study of selected resurfacing cycles with high traffic volume shows the resurfacing effectiveness (Pavement 70 Interval) decreases more than 10% (1 year) at every 5-point drop of COPACES rating when resurfacing is conducted at a rating less than 70. Results indicate the resurfacing delay has significant negative impact on resurfacing effectiveness. More data, especially projects with different traffic volumes, are needed to support this finding.

17) A case study was conducted on S.R. 26/U.S. 80 in Chatham County (near the Port of Savannah) using the data collected by Ga Tech's sensing van between 2011 and 2016 to provide consistent and quantitative assessment on the increased construction costs and user costs caused by a pavement resurfacing delay. Results show, on average, that deep patching costs increased approximately $4,300 per lane-mile per year when the rating dropped from 75 in FY 2012 to 31 in FY 2015. This means an additional cost of $4,300 needs to be included in milling and resurfacing projects for deep patching with one-year delays in resurfacing. With extensive deep patching (37.7% of the wheel path), the deep patching costs ($24,505) are approximately 37% of the 1.5-in

resurfacing costs in 2016. The performance of the subsequent resurfacing cycle may be reduced with the extensive patching. In addition, maintenance activities, such as patching potholes and spot overlay prior to resurfacing, are needed to address safety concerns and maintain the expected level of service. This will increase the work load on a limited number of maintenance crews. These all indicate the importance and cost effectiveness of timely performing the necessary rehabilitation.

18) The user costs, computed as Vehicle Operating Cost (VOC) based on International Roughness Index (IRI), increased by approximately 0.2% ($2,400) per year as the COPACES rating dropped from 75 in FY 2012 to 31 in FY 2015. There was a significant increase (1%; $13,000) from FY 2015 to FY 2016. The user cost is 16 times the construction cost, which includes deep patching, and milling and resurfacing.

19) Historical COPACES data on S.R. 26 shows the rating dropped rapidly (more than 10 points per year) from 65 in FY 2012 to 31 in FY 2015. It shows pavement deterioration occurs at an increasing rate in the later stages; thus, it is critical not to defer pavement preservation for too long. With the rapid deterioration, the timing or opportunity for pavement preservation can be missed, especially with bi-annual surveys, and much more expensive rehabilitation would be needed.

To further study the pavement service interval/deterioration in Georgia, the following need to be considered:

1) Interstate highways are a significant capital investment; however, limited interstate pavement condition data have been collected due to safety concerns. There is a need to develop an automated method using computer vision and/or laser technology to collect pavement condition data on Georgia's interstate highways. Safety and technology should be focused upon when acquiring more and better data for the interstate highways.
2) GDOT is in the process of implementing a new route priority system (critical, high, medium, and low priority) based on traffic volume, functionality, etc. As the pavement design, traffic load, and required level of service for each category can be different, there is a need to develop a resurfacing strategy for each category based on its actual deterioration behaviors.
3) The long-life pavements, especially pavements with multiple cycles, could be further

studied to identify the factors (e.g. timely pavement preservation for pavements with specific base materials, traffic volumes, and designs) contributing to the extended pavement service interval. The pavements that last perpetually by only applying resurfacing on a timely basis could be studied to determine the maximum number of resurfacing cycles that could be achieved practically.

4) To get a quantitative assessment of the reduced resurfacing effectiveness caused by pavement resurfacing delay, it is recommended that long-term performance monitoring be continued on S.R. 26 after its recent delayed milling and resurfacing.

5) Besides a composite rating, further study is needed to identity additional indicators, like load-induced distresses, deterioration rates, etc., that can be used to more adequately refine GDOT's current treatment criteria and timing (the performance indicators, like COAPCES ratings, and the threshold, like 70).

6) Additional variables, such as the pavement structure design, materials, subgrade, environments, and ESAL are recommended for inclusion in future performance studies to gain in-depth understanding of the factors impacting pavement performance, even though these data are difficult to obtain.

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1 INTRODUCTION

1.1 Background and Research Need

According to the roughness data collected by various states and reported to the Federal Highway Administration, Georgia consistently has been considered one of the states with the smoothest pavements in the country (Swanlund, 2000). This is attributed to GDOT's good practices on pavement condition evaluation, preservation, and management, especially GDOT's establishment of a standardized pavement condition evaluation system (PACES) in 1986. PACES provides the basis for consistent pavement performance monitoring, an active annual pavement preservation program, a data-driven method of determining the best pavement preservation method (i.e., treatment criteria), prioritization of the projects (e.g., rating, AADT, etc.), and allocation of the maintenance and rehabilitation funding. Since the 1980s, the Georgia Department of Transportation (GDOT) has developed an annual pavement preservation program that uses of thin-overlay (e.g., 1.5") at the right time (e.g., a rating of 70) to cost-effectively extend pavement service intervals (Tsai et al., 2004; Tsai et al., 2009). GDOT has conducted its annual pavement condition evaluation based on its Pavement Condition Evaluation System (PACES) (GDOT, 1993) established in 1986. These rich pavement performance data from FY 1986 to FY 2014 are extremely valuable for revealing the actual pavement performance in Georgia. There is a need to study the actual pavement performance to answer the question on how long the in-service pavement lasts using GDOT's rich historical pavement condition evaluation data. The pavement service intervals had been previously studied in 2006, and this project would include an additional 8 years of data (FY 2007 – FY 2014). Due to funding shortages, GDOT's pavement resurfacing projects have been substantially delayed in recent years, and many projects have not been resurfaced at their originally planned timing (e.g., a rating of 70). There is a need to study the pavement resurfacing delay situation and the impact of pavement resurfacing delay on the reduction of the resurfacing service interval and the increase in construction and user costs.

1.2 Significance of Research

The research outcomes, including the actual pavement performance and distress characteristics for Georgia by region and by traffic category will improve GDOT's life cycle cost analysis on current pavement design with actual performance; it will enhance pavement management and long-term planning. The research outcomes from studying the actual impact of delayed pavement preservation will enable GDOT to critically assess its pavement preservation practices and explore solutions to mitigate pavement resurfacing problems. Understanding the actual pavement resurfacing delay situation will provide GDOT the information needed to allocate the funding needed for clearing the backlog of resurfacing projects and to justify funding needs.

1.3 Research Objectives and Scope

The objectives of this research project were 1) to study the actual pavement performance of GDOT's in-service pavements using GDOT's rich historical pavement condition evaluation data collected from FY 1986 to FY 2014; 2) to study the pavement resurfacing delay situation; and 3) to study the impact of pavement resurfacing delay with a special focus on the pavement resurfacing effectiveness/life, and increases of construction and user costs. This project consisted of five work tasks as follows:

1) Work Task 1: Gather, review, and process historical pavement condition data, traffic data, and maintenance records on selected projects for analyses. This task gathered the data necessary to study actual pavement performance/service interval in Georgia. The research team worked with GDOT and gathered historical PACES data from 1986 to 2014 and traffic data and maintenance records on selected projects. The research team processed the historical PACES data to construct a time-series pavement performance curve for each project based on the project termini. If the project termini had to be changed, a project rating was recomputed based on the original project termini and segment survey data, if available. Through this process, a complete time-series pavement performance curve for each project was constructed for determining pavement resurfacing service interval.
2) Work Task 2: Analyze the actual pavement resurfacing service interval in Georgia. This task analyzed pavement resurfacing service intervals in Georgia using 29 years of pavement condition data. The research team first determined pavement resurfacing service interval with a confidence level for each project using a set of rules established in a previous study (Tsai et al., 2009). This process involved manually reviewing the completeness of the starting point, ending point, and trend of the time-series pavement rating for each resurfacing cycle and assigned a confidence level (high, medium, or low) based on the established rules.

The confidence level indicates the data quality and reliability of a pavement's service interval and helps to eliminate the pavement lives with unclear or insufficient condition data (e.g., unclear starting and/or ending points). The pavement resurfacing lives with a high confidence level were then analyzed by different factors, such as working district, functional class, AADT category, RBR, etc. In addition, the pavement distress conditions on selected projects were analyzed to better understand distress propagation behavior on the projects with typical pavement resurfacing service interval.

3) Work Task 3: Study current pavement resurfacing delay conditions. This task studied the backlog of pavement resurfacing projects based on the PACES data collected in 2014. The backlog is presented by route type (interstates and non-interstates) and by working district. This historical backlog was analyzed to understand the trend (or changes) in the delay.
4) Work Task 4: Assess the impact of the delayed pavement resurfacing. This task assessed the impact of the delayed pavement resurfacing on the pavement performance, the construction cost, and the user cost, etc., using historical COPACES data, 3D pavement data, and treatment criteria provided by GDOT's engineers. The research team worked with the Office of Maintenance to select projects for studying in-depth the consequences of delayed resurfacing. This includes the reduction of pavement service intervals and increase of construction costs caused by delayed pavement resurfacing.
5) Work Task 5: Prepare final report. This task documented, organized, and summarized all research findings obtained in the previous work tasks.

1.4 Organization of this Report

This report is organized as follows:

1) Chapter 1 introduces the background, significance, scope, objective, and work tasks of this project.
2) Chapter 2 introduces GDOT's pavement management practices, including its pavement condition evaluation system, the pavement preservation program, and the risk-based pavement preservation program implemented in 2014.
3) Chapter 3 describes the data processing steps for determining pavement service interval. These include a) the steps for filtering, grouping, and reconstructing ratings to generate a

time-series pavement performance curve and b) the manual review process to determine pavement service interval with a confidence level.

4) Chapter 4 summarizes the pavement resurfacing service interval by different factors, including working district, traffic category, functional class, etc.
5) Chapter 5 presents the analyses of the distresses on Georgia's roads, including the predominant distresses and their deterioration.
6) Chapter 6 presents the pavement condition at the network-level and the delayed pavement resurfacing (i.e., resurfacing backlog) using COPACES data. In addition, the RBR was studied to better understand GDOT's resurfacing practices.
7) Chapter 7 discusses the impact that delayed resurfacing has on pavement service interval, including a reduction in pavement service interval and an increase in construction costs (e.g., additional patching, strip seal, deep patching, etc.). The historical data and the video log data collected on S.R. 26 in Chatham County from 2011 to 2015 with a rating changing from 75 to 45 were analyzed to compute the additional construction and user costs caused by delayed resurfacing.
8) Chapter 8 summarizes the findings of this project and makes recommendations.

2 PAVEMENT CONDITION SURVEY AND MAINTENANCE/REHABILITATION PRACTICE

Georgia has been consistently rated as one of the states with the smoothest pavements in the United States (Swanlund, 2000), and its pavement management practices play a vital role in cost-effectively maintaining its pavements in a good condition; Georgia's pavements have good ride quality for the state's 18,000-centerline-mile pavements. This chapter introduces GDOT's pavement management practices. The practices include a standardized pavement condition evaluation system for monitoring the pavement condition and an active annual pavement preservation program focusing on effective use of thin-resurfacing (e.g., 1.5-in) at the right time to cost-effectively extend the pavement service interval. Over the years, GDOT has developed procedures and tools to systematically 1) evaluate pavement condition, 2) determine the preservation method, estimate costs, and 3) prioritize the pavement preservation projects based on condition data to preserve the pavement at the right time for maximizing the performance. More recently, the Moving Ahead for Progress in the 21st Century Act (MAP-21), signed into law in 2012, requires state departments of transportation (DOTs) to develop risk-based and performance-based asset management plans for pavements and bridges on the National Highway System to improve or preserve the condition of the assets and the performance of the system. In response to state legislation requirements, GDOT has enhanced its pavement preservation program by incorporating risk considerations, including road users, freight traffic, and mobility, into the pavement preservation project selection program (GDOT, 2012; Tsai et al., 2014). The core elements of the risk-based pavement preservation program, including risk factors and a modified rating, are described in this chapter.

Each year, GDOT surveys its 18,000 centerline-miles of roadway based on the Pavement Condition Evaluation System (PACES) (GDOT, 1993), and the data is used to identify the locations and timing for pavement resurfacing. GDOT's resurfacing program is designed to resurface the pavements at the right time (i.e., at a rating of 70) to provide a 10-year pavement resurfacing service interval and minimize the use of expensive rehabilitation. The resurfacing program was designed to sustain its highways by resurfacing 10% of the pavements each year; it assumes a resurfacing service interval of approximately 10 years, although, many pavement resurfacing projects have been delayed in the past decade. This chapter reviews GDOT's pavement condition evaluation system and annual pavement preservation program.

2.1 Computerized Pavement Condition Evaluation Systems (COPACES)

GDOT's pavement management practice is based on its pavement condition evaluation system, which provides essential data for determining treatment method, estimating costs, and selecting projects. Since 1983, GDOT has conducted annual pavement condition evaluations on its entire 18,000-centerline-miles of state routes based on the Pavement Condition Evaluation Systems (PACES) (GDOT, 1993) developed by GDOT. PACES was enhanced and upgraded to the Computerized Pavement Condition Evaluation Systems (COPACES) in 1998 for a paperless system that enhanced data quality and improved the efficiency of the field data collection system (Tsai & Lai, 2001; Tsai & Lai, 2002). COPACES surveys are performed by GDOT's engineers during the winter (September to February of the following year), when there are no construction projects. By doing so, it does not need to employ additional resources. In addition, engineers can review the condition of roadways they manage in the field to better asses needs. Surveys conducted using COPACES involve recording the severity and extent of various types of pavement surface distresses, such as cracking, rutting, potholes, raveling, etc., to derive a pavement condition representing each mile-long pavement segment (GDOT, 1993). The distresses recorded for all the segments (which are one mile long) are then aggregated/averaged to obtain the representative pavement condition for a project (typically several miles long). A COPACES performance rating scale of 0 to 100 (with 100 representing the pavement in excellent condition) is then computed based on the extent and the severity level of each distress for each segment and project. To enable uniform, impartial data collection and reporting across Georgia, COPACES establishes standardized nomenclature for distresses and defines their respective severity levels and measurement method. There are ten distresses surveyed in COPACES. They are rutting, load cracking, block cracking, reflective cracking, raveling, edge distress, bleeding/flushing, corrugation/pushing, loss of section, and potholes/patches/localized failure, as listed in Table 2.1.

Table 2.1 Distresses in COPACES

Distress	Unit	Severity	Sample Location
Load Cracking	%	1, 2, 3, 4	100-ft
Block Cracking	%	1, 2, 3	100-ft
Reflection Cracking	Number of cracks Length in foot	1, 2, 3	100-ft
Edge Distress	%	1, 2, 3	1-mie
Rutting	1/8 inch	-	100-ft
Patches/Potholes/Local failure	Number	-	1-mile
Bleeding	%	1, 2, 3	1-mile
Raveling	%	1, 2, 3	1-mile
Corrugation	%	1, 2, 3	1-mile
Loss of Section	%	1, 2, 3	1-mile

A walking survey is conducted to survey cracking; t it covers a 100-foot representative sample within a mile-long segment. This sampling method is used because it is far too labor- and time- intensive to record cracking for an entire mile-long segment. A 100-foot sample location that represents the norms of the segment (not the best or worst) is selected based on the surveyor's best judgment after he/she travels the entire segment. The distress types are categorized and associated with potential causes of the pavement defects so the data can be used for determining the treatment method. For example, longitudinal cracking and fatigue cracking occurring in the wheel path are considered as load-related cracking (load cracking), and block cracking is considered as non-load-related cracking due to aging and weathering. Besides load cracking, block cracking, reflective cracking, and rutting, all other distress types are measured for the entire 1-mile (rather than 100-ft sample location). In addition, a hierarchical data collection procedure based on the Area Office (AO), District Office (DO), and General Office (GO) is in place to ensure the decisions on the pavement treatment are based on quality data. A COPACES survey is first performed by the Area Offices for all the routes for which they are responsible. Projects with a rating of 75 or below, which potentially need resurfacing, are then surveyed by the District Offices and by representatives from the State Maintenance Office (General Office). Once DO and GO concur that the project warrants treatment, the process of preparing a pavement preservation (thin resurfacing) project begins.

2.2 Pavement Preservation Program

Before the 1970s, Georgia had the worst roads in the Southeast, so GDOT initiated a program to perform pavement preservation actions (Tsai et al., 2008). Since the 1970s, Georgia has been one of the leading states in the country with an active pavement preservation program, focusing on using thin-resurfacing (e.g., 1.5-in overlay) to cost-effectively extend a pavement's service life. The concept is to apply thin-resurfacing on 10% of the roads each year so that the entire network is resurfaced approximately every 10 years, assuming the average resurfacing life is 10 years. Over the years, GDOT has established a collaborative decision-making process to effectively identify and prioritize pavement preservation needs at the network-level (Tsai & Lai, 2001; Tsai & Lai, 2002; Tsai et al., 2004; Tsai et al., 2005; Tsai et al., 2008). The following steps describe GDOT's pavement preservation practices with a focus on the resurfacing program:

- Step 1: Perform annual pavement condition evaluation (Area, District, and General Offices)
  As described in Section 2.1, GDOT has conducted annual pavement condition evaluations on its 18,000 centerline-miles of state routes since 1986; the data is used to support pavement management decisions.
- Step 2: Prepare and prioritize District let projects (District Offices)
  The District Offices are responsible for compiling a project list of all the state-maintained highways that meet the conditions necessary to be recommended for treatment and places them on a priority list based on various factors, such as severe pavement distresses, the number of people serviced based on AADT, safety issues, potential rapid pavement deterioration due to increased traffic volumes, etc. First, the pavement preservation treatment criteria, as shown in Figure 2.1, provide guidance for an appropriate treatment method based on pavement distresses. The available treatment methods include crack filling/sealing, strip seal, chip seal, overlay, mill + spot overlay, mill + overlay, and level + overlay. Microsurfacing was used previously. Fog seal is currently under study to mitigate raveling problems on interstate highways. A treatment method is finalized for each project based on the experience of each district, and a preliminary cost estimate is prepared based on anticipated preservation work and other associated work. The project list is submitted to the General Office. In the past, this was a time-consuming manual process; the District Offices had to manually compute project ratings, determine the treatment method, estimate the costs, and prioritize the projects.

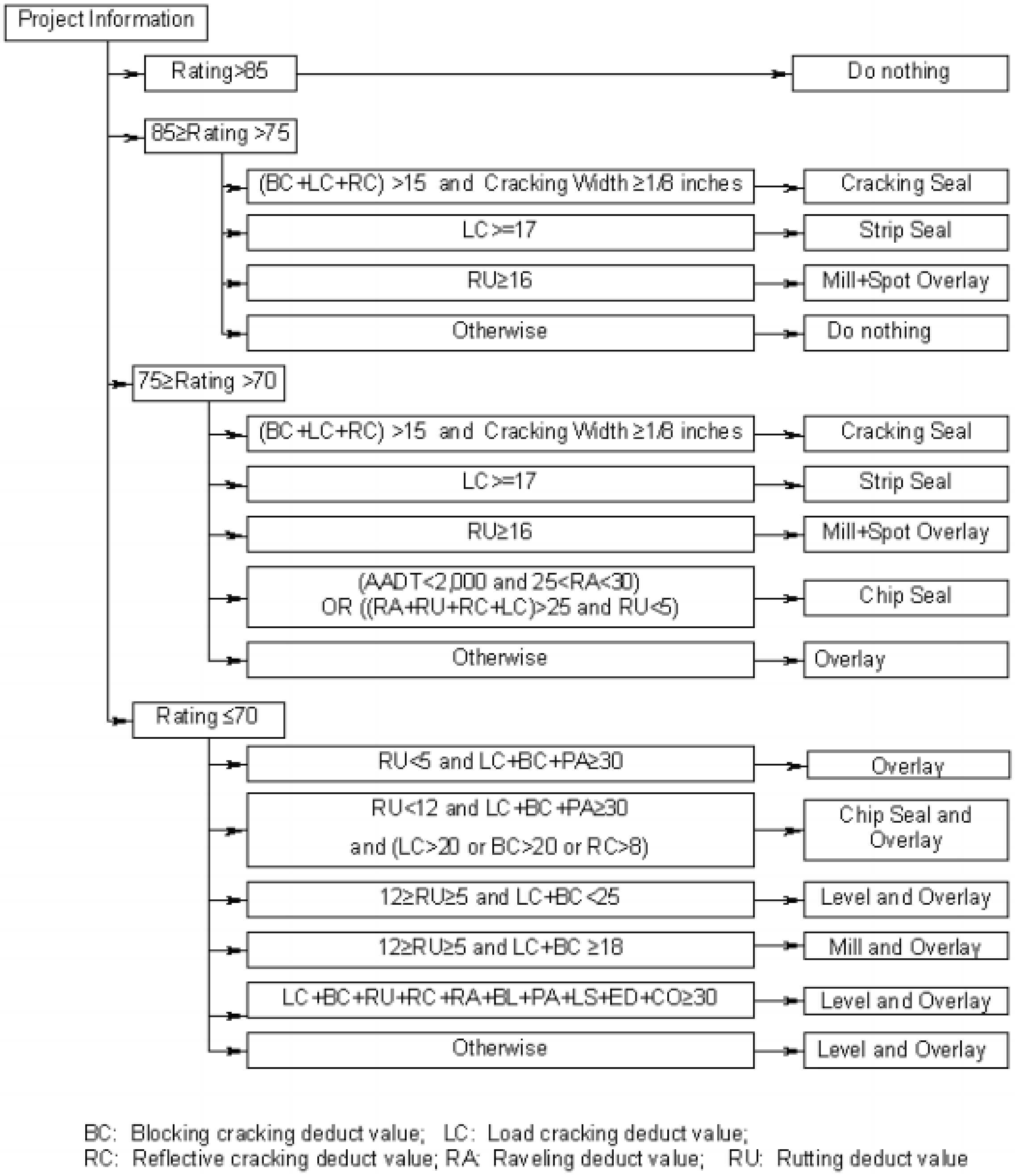


Figure 2.1 GDOT's treatment criteria

Since the implementation of the Georgia Pavement Management System (GPAMS) in 2004, the system has been automated. In 2004, the annual Project Selection module has been used by the District Offices to further standardize and streamline the processes of treatment determination, cost estimates, and project prioritization. More importantly, the module provides the flexibility for the District Offices to make necessary modifications and refinements to a project's priority, treatment method, and treatment costs based on their engineering judgments. This method is extremely valuable and contributes greatly to GDOT's highly successful pavement preservation program.

- Step 3: Finalize and prioritize state let projects (General Office)

Each year, the General Office receives designated federal and state funds for preserving state highways and allocates the funds based on needs. The General Office uses GPAMS to compile all the project lists from GDOT's seven districts and prioritizes the projects on a statewide level based on various factors, such as funding availability, district priority, workload balance among the seven working districts, and the funding balance among the state's fourteen congressional districts. This process was extremely complicated and time-consuming. Consequently, a Funding Allocation module was implemented in 2004 and has been used by the General Office to allocate the users-specified funding. The system considers district priority, project rating, and constraints (including funding availability, balancing workload among working districts and funding among congressional districts).

Figure 2.2 shows different statewide funding distributions and project selection criteria based on GDOT's operations.

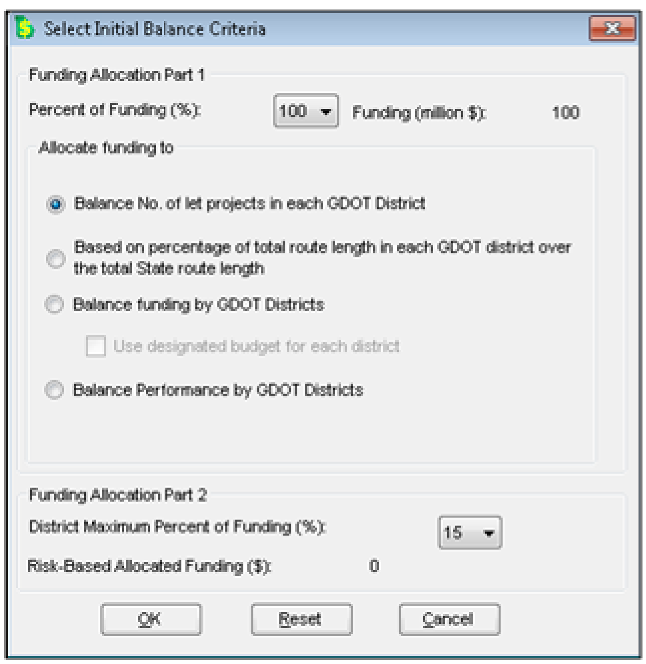


Figure 2.2 Statewide funding distribution and project selection criteria

For example, the managers in the General Office can choose to balance funding by GDOT districts using designated budgets for each district. Based on this criterion, the manager specifies the funding distributed to each district. After taking into account the district priority and statewide funding constraints, the final list of preservation projects for let can then be completed, as shown in Figure 2.3. Box A in Figure 2.3 shows the final pavement preservation let projects. The total number of the let projects is 90, covering about 1,882 lane-miles (3030 km), and the total cost is $87 million dollars. The additional pavement preservation projects are also identified. As shown in Box B, the additional funding need is $57 million dollars and covers 1,246 lane-miles (2006 km). The system enables the General Office to perform "what-if" analyses to evaluate different scenarios that can meet pavement maintenance requirements.

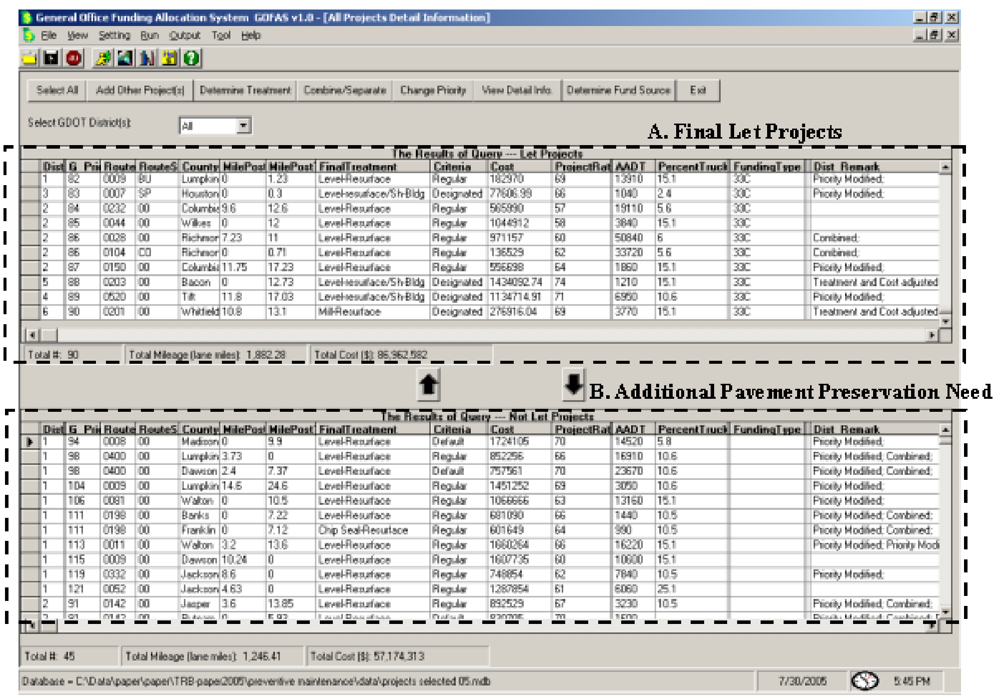


Figure 2.3 Final statewide pavement preservation let projects and the additional needs

- Step 4: Prepare pavement preservation package (District office)

  Once the statewide priority list is established, the Districts are advised to begin preparing their detailed pavement maintenance package with a more accurate treatment determination and cost estimate; this is then submitted to the General Office four months in advance of scheduled letting of projects for roadway preventive maintenance. The recommended treatment methods are also reviewed and approved by the General Office and the State Lab Office.

- Step 5: Prepare and arrange bid projects (General Office)
  The General Office compiles all the data from the District Offices and formats the information into documents submitted to the Office of Contracts Administration, which completes the packages for letting the contracts. Pavement maintenance and rehabilitation contracts are put out to bid year-round and statewide.

Besides determining the pavement preservation let projects described above, the District Offices need to identify the pavement preservation methods, such as crack seal, strip seal, etc., that are carried by internal maintenance forces. In the past, these planned routine pavement preservation tasks were transferred into GDOT's Highway Maintenance Management System (HMMS); the tasks' progress was then monitored and reported weekly using HMMS. GDOT currently uses Maintenance Manager™ by AgileAssets Inc. for tracking the tasks' progress.

2.3 Risk-based Pavement Preservation Program

In response to the Moving Ahead for Progress in the 21st Century Act (MAP-21) requirement, GDOT has developed and implemented a risk-based pavement preservation program that incorporates risk considerations into the pavement preservation project selection and prioritization process. During the project selection and prioritization process, GDOT currently considers the impact of each pavement preservation project on road users, freight traffic, and mobility in the area surrounding the project. Three risk factors, which are represented by the annual average daily traffic (AADT), truck percent, and county population, have been identified by GDOT's expert panel (GDOT, 2012; Tsai et al, 2014). The intent of considering these risk factors is to select pavement preservation projects that have the most risk (i.e., they have greater impact on road users, movement of freight, and mobility in the surrounding areas). At the core of the pavement preservation program is a modified rating to seamlessly incorporate these risk factors into the pavement preservation program. The expert panel from GDOT has developed an initial matrix for use in evaluating the consequences of the risk factors based on their values, as shown in Table 2.2. A project with a larger risk value is considered as having a greater risk compared to a project with a smaller risk value. For example, a project with a higher AADT would have greater risk (or impact) if its maintenance, rehabilitation, and reconstruction (MR&R) is delayed.

Table 2.2 Risk Values for AADT, Truck Percentage, and Population

Risk Value	**AADT**	**Truck %**	**Population**
0.6	>100,000		>600,000
0.5	50,000 -100,000	>=18%	300,000 – 599,999
0.4	40,000 – 49,999	12% - 18%	200,000 – 299,999
0.3	25,000 – 39,999	>=6% - 12%	100,000 – 199,999
0.2	15,000 – 24,999	< 6%	>50,000 – 99,999
0.1	7,000 – 14,999		< 50,000
0	< 7,000		

The risk values are then incorporated into the COPACES rating, which represents the overall pavement condition, to generate a modified-rating for selecting and prioritizing the pavement preservation projects. As shown in Equation 1, the modified-rating is computed by dividing the COPACES rating by one plus the total risk values of AADT, truck percentage, and population. For example, a project with a COPACES rating of 75, an AADT of 75,000, a truck percentage of 10%, and a population of 500,000 would have a risk-based rating of 32.6 (75 / (1+0.5 + 0.3+0.5)). The design is intended to give higher priority (i.e., lower rating) to the projects with higher risk (e.g., high AADT). This modified-rating, which takes into account the OM-identified risks, is then used for prioritizing projects at the District Offices and for allocating funding at the General Office.

$$Modified\_Rating = \left(\frac{COPACES\ Rating}{1+(Risk\ Value_{AADT}+Risk\ Value_{truck\ percentage}+Risk\ Value_{population})}\right) \quad \text{(Equation 1)}$$

- COPACES Rating: a rating (0-100) represents the overall pavement condition.
- Risk Values: a number ranges from 0 to 0.6 that represents the effects of each factor (see Table 2.2). A larger number indicates more risk concerns.

Figure 2.4 depicts the existing collaborative decision-making processes performed by the District and General Offices within the risk-based pavement preservation program. The modified-rating is used by the District Offices for prioritizing the projects and by the General Office for allocating funding without changing the original processes.

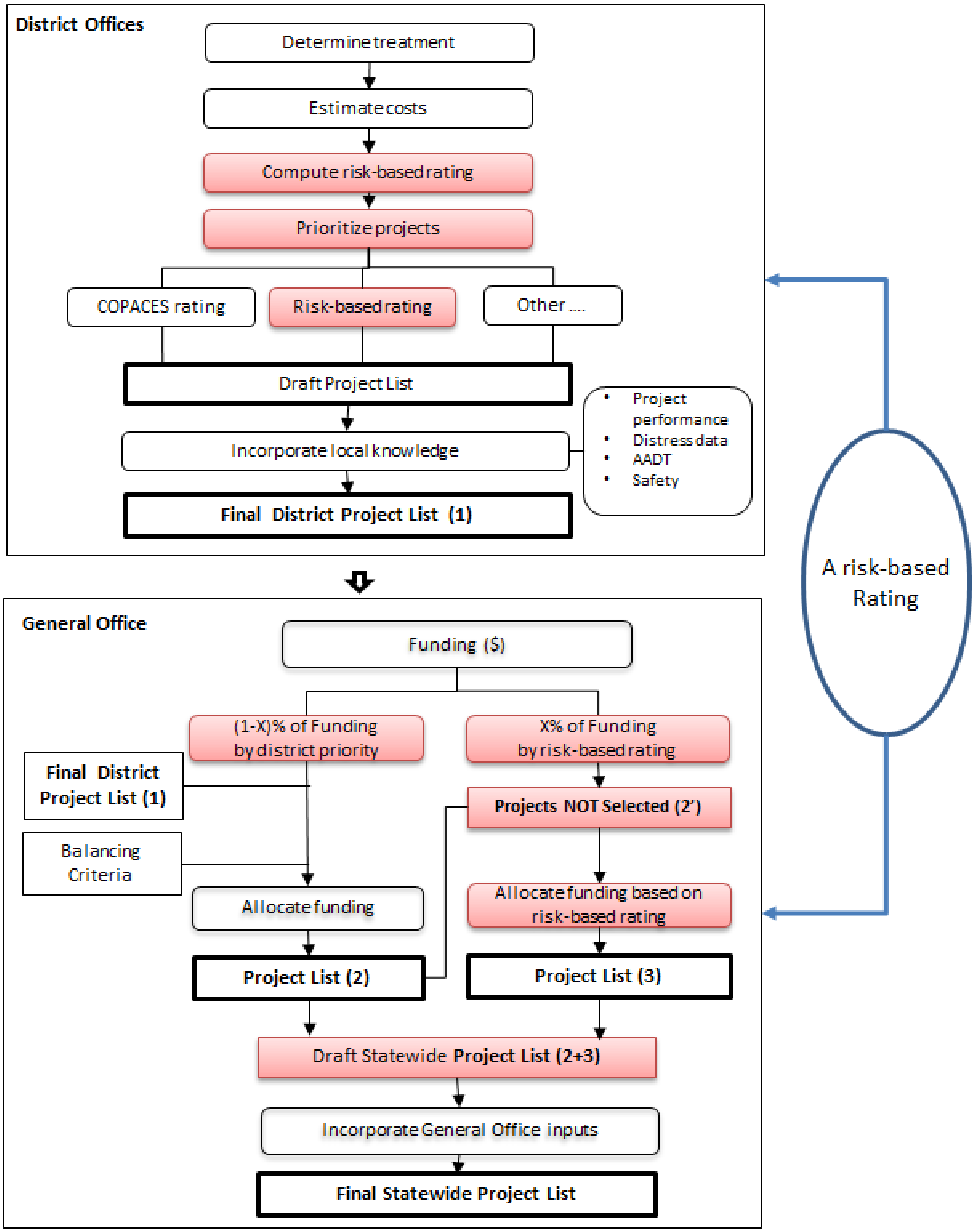


Figure 2.4 Decision-making process for a risk-based pavement preservation program

2.4 Summary

As one of the leading states consistently rated as having the smoothest pavements in the county, GDOT has developed good pavement condition evaluation, preservation, and management practices to successfully maintain its 18,000 centerline miles of pavements in good condition with good rideability. These include a standardized pavement condition evaluation system and an active annual pavement preservation program that support a) consistent pavement performance monitoring, and b) a consistent, data-driven determination of the pavement preservation methods (i.e., treatment criteria), prioritization of the projects (e.g., rating, AADT, etc.), and allocation of the funding. It enables District Offices and the General Office to collaborate on making pavement-preservation decisions. More recently, GDOT has developed and implemented a risk-based pavement preservation program for meeting the MAP 21 (Moving Ahead for Progress in the 21st Century Act) asset management requirement by considering the impact of a pavement preservation program on road users, freight logistics, mobility in the area surrounding the project, and pavement condition. Since 2014, GDOT has used a modified-rating that incorporates AADT, truck percent, and population into its COPACES rating for ranking pavement preservation project selection and funding allocation.

3 DATA AND DATA PROCESSING

In this study, historical COPACES data collected from FY 1986 to FY 2014 were used to study the actual pavement performance (or service interval/life) and deterioration. A completed time-series pavement performance curve was established for each project using historical COPACES data to determine the pavement service interval. While COPACES data was collected annually based on GDOT's pavement distress and survey protocol, analyzing pavement service interval using this data is challenging. First, the project termini in COPACES data changes over the years, which causes problems in establishing a time-series rating history. For example, two adjacent projects can be combined into one project because they were resurfaced at the same time. Second, there are variations in the ratings; that is, a rating may not always have a decreasing trend, even without maintenance activities. Third, the rating may not be available every year, especially immediately before and after resurfacing. In this study, to ensure the pavement service intervals were studied using quality data, steps were taken to process the data for establishing an accurate time-series rating history. In addition, a set of rules was developed to determine pavement service intervals according to their confidence levels (e.g., high, medium and low). This ensured the analysis outcomes were derived based on high-quality data (with high confidence level). This chapter describes the steps undertaken for determining pavement service interval, including the definition of pavement service interval, the processes for establishing the time-series pavement performance curve, the rules for determining pavement service interval with a confidence level (e.g., high, medium or low), and a summary of the processed pavement service intervals.

3.1 Definition of Pavement Service Interval

Pavement resurfacing service interval can be defined in multiple terms. The common definitions are (1) the time span from a resurfacing activity until the next resurfacing or (2) the time span for a newly resurfaced pavement to reach a serviceability threshold value (e.g., International Roughness Index (IRI), rating, etc.) (NCHRP, 2004). The first definition represents the time between two consecutive resurfacings, and it can be affected by the funding availability, resurfacing policy, etc. The second definition measures the pavement performance in terms of reaching a serviceability threshold value and does not affect the funding availability. Therefore, the following two types of pavement service interval, as defined in previous studies (Tsai et al., 2009; Tsai et al., 2012), are studied in this project.

- Pavement Resurfacing Interval: the time span from a newly resurfaced pavement until the next resurfacing activity.
- Pavement 70 Interval: the time span from a newly resurfaced pavement to a rating of 70. This is designed to provide a consistent performance measure.

3.2 Data Processing

Historical COPACES data were processed and clustered to establish a time-series pavement performance curve for each project. The following describes the process:

- Data filtering

  COPACES data were filtered to remove the projects with no rating, the projects with no segment data, and the projects that are concrete pavements. This was to ensure the project data were valid, i.e., with a rating and segment data. After the filtering, 87,188 out of 82,533 survey projects remained.
- Grouping/Clustering projects

  The 82,533 projects were grouped/clustered based by geographical location to establish the time-series pavement performance curve based on location. The same projects surveyed in different years could have slightly different project termini, as shown in Figure 3.1; these projects were grouped using RCLINK and beginning and ending mileposts to establish the time-series pavement performance curve. Because the project termini can change slightly over the years, a buffer was included to group the projects. The projects were grouped based on FY 2013 projects' termini (which were more recent and had more survey projects). For this study project, a total of 82,533 projects were processed (including reconstructing ratings for 4,508 projects) and clustered into more than 3,900 groups.

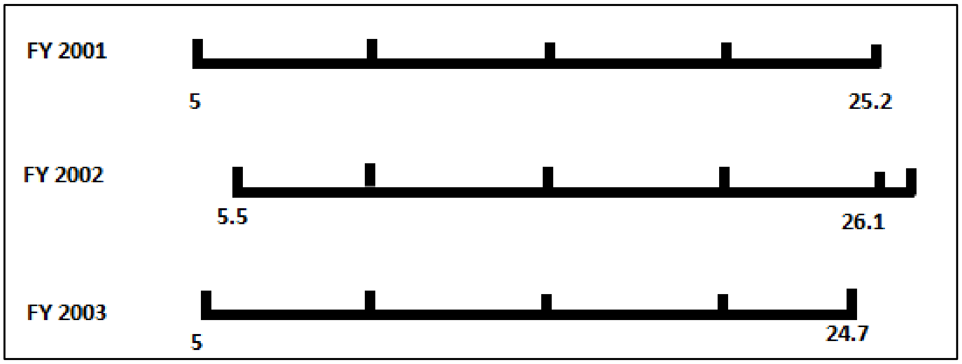


Figure 3.1 Illustration of clustering projects

- Reconstructing rating

  The project termini can change over the years. For example, a project from MP 0 to MP 16 may be surveyed differently (e.g., MP 0-13 and MP 13-27) in the previous year for various maintenance reasons. In such cases, a project from MP 0 to MP 16 can be reconstructed based on segment data. Figure 3.2 shows an example of reconstructing a project. A route was surveyed as two projects, MP 0-16 and MP 16-27, in FY 2014 because resurfacing was applied on MP 0-16. However, it was surveyed differently in FY 2013 (MP 0-13 and MP 13-27). To establish the time-series rating history for the project from MP 0 to MP 16, a project rating can be reconstructed using the segment data in FY 2013. The segments from MP 0 to MP 16 from different surveys are combined as one project and a project rating is computed for this new project.

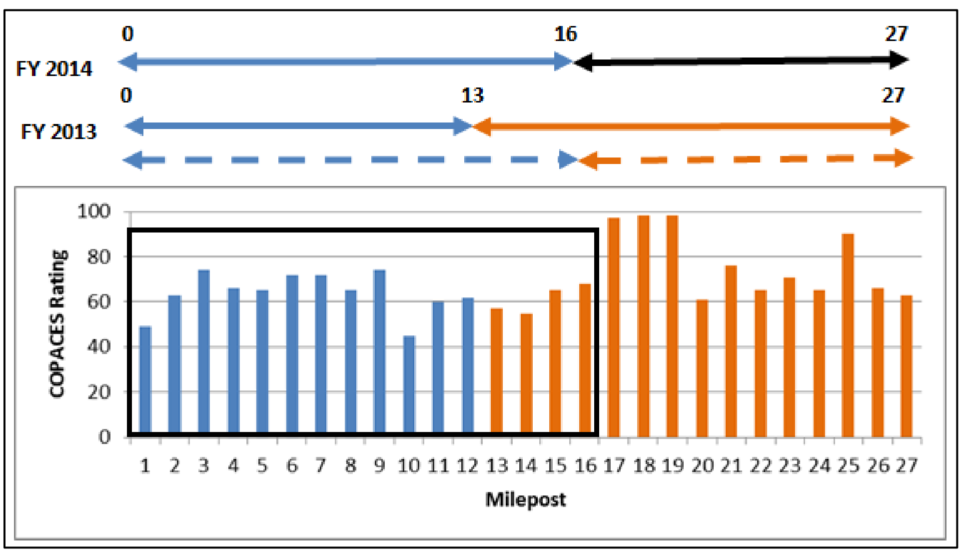


Figure 3.2 Illustration of reconstructing a project

3.3 Rules for Determining Pavement Service Intervals

An evaluation system was used for determining pavement resurfacing service interval with a confidence level (Tsai et al., 2009; Tsai et al., 2012). Figure 3.3 illustrates the concept of the confidence evaluation system. A series of indicators, as listed in Table 3.1, including year start (YS), year end (YE), trend in the middle (TM), year to reach a rating of 70 (70Y), and Rating before Resurfacing (RBR), were designed to describe the data characteristics in each pavement resurfacing cycle. These factors, including YS, YE, and TM, considered in the confidence level evaluation system, were then rated using the decision rules established by reviewing transportation agencies' pavement condition evaluation and pavement preservation practices and by discussing the indicators with GDOT pavement engineers (Tsai et al., 2009; Tsai et al., 2012). Appendix I lists the rules for determining the confidence level for each indicator. For example, as mentioned previously, the DO and/or GO Office in GDOT will survey the pavements with a rating of 75 or less to validate the pavement rating provided by an AO. If the pavement rating is confirmed to be 70 or less, it is put on the waiting list for treatment. Therefore, the existence of multiple offices' surveys is a strong indication that a pavement needs to be treated. The year after multiple offices have surveyed the pavement can be recognized as the YE of the current resurfacing-cycle, as well as the YS of the succeeding resurfacing cycle, with high-confidence. The assigned confidence levels of those indicators include High (H), Medium (M), Low (L), or Incomplete (I). The philosophy of developing a confidence level evaluation method is that the high-confidence service intervals can be used in resolving ambiguities. Therefore, the most restrictive rules are applied to high-confidence levels. After determining the confidence level of each indicator (e.g., YS), indicators are combined to determine the pavement performance characteristics (e.g., service interval/life) and the corresponding levels of confidence. The confidence level of a resurfacing cycle is defined as the minimum confidence level of YS, YE, and TM. For example, if the confidence levels of YS, YE, and TM are H, H, and M, respectively, the confidence level is M. Similarly, there are five confidence levels, including H, M, L, U, and I. Only high-confidence life curves are used in the statistical analyses in subsequent chapters. For the detailed definition and criteria, see Appendix I (Tsai et al., 2009; Tsai et al., 2012).

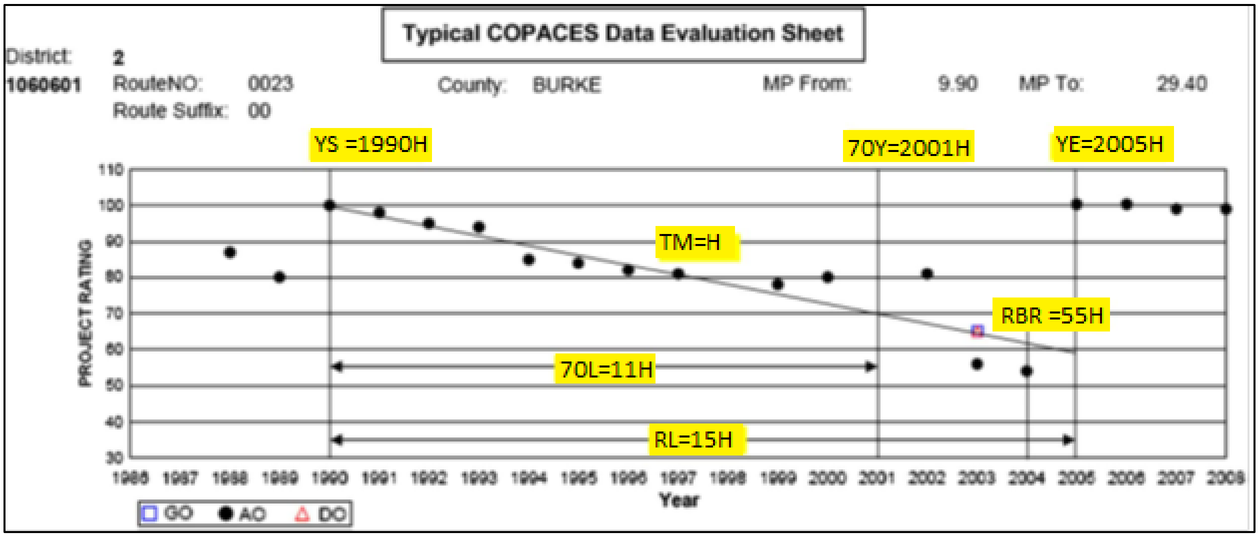


Figure 3.3 Determining pavement service interval a confidence Level (Tsai et al., 2012)

Table 3.1 Definition of Terms

Variable Description	Manual Variable Abbreviation
Pavement Resurfacing Interval	RL
Year Start	YS
Year End	YE
Trend in the Middle	TM
Pavement 70 Interval	70L
Year to reach a rating of 70	70Y
Rating before Resurfacing	RBR

3.4 Summary of Processed Data

Data for more than 87,000 pavement survey projects covering 29 years were collected. These projects were clustered according to their geographical locations into more than 3,900 projects with pavement performance curves. There projects were reviewed based on the rules described in this chapter for determining their pavement life. Figure 3.4 shows an example of the reviewed result for a project. The project has two resurfacing cycles. The first cycle has a Pavement Resurfacing Interval of 8 years and a Pavement 70 Interval of 6 years. The start year and end year can be clearly identified and the trend is good; thus, the Pavement Resurfacing Interval has a high confidence level. As of 2014, the second cycle has not been determined because the pavement has not yet been resurfaced; thus, a Pavement Resurfacing Interval is not available. However, it had reached a rating of 70. Thus, the resurfacing cycle has a Pavement 70 Interval of 6 years with a high confidence level. The data extracted from the pavement performance curves is summarized in Table 3.2. Among the 3,900 projects, only approximately 1% of all projects have a high-confidence level, mainly as a result of incomplete historical data. In the subsequent chapters of this study, 370 high-quality pavement resurfacing cycles are used for statistical analysis.

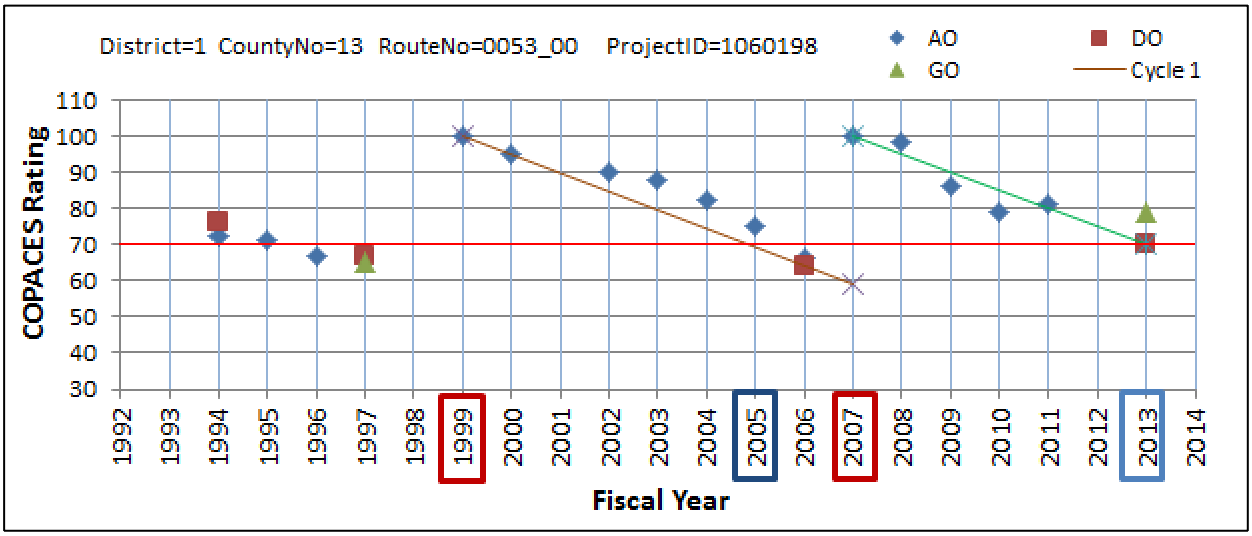


Figure 3.4 An example of determining pavement service interval from the performance curve

Table 3.2 An Example of Pavement Service Interval Data

		YS	YE	TM	RL	70Y	70L	RBR
Cycle 1	Value	1999	2007		8	2005	6	65
	Confidence Level	H	H	H	H	H	H	M
Cycle 2	Value	2007	2013		-	2013	6	64
	Confidence Level	H	I	M	I	H	H	H

4 ANALYSIS OF PAVEMENT SERVICE INTERVAL IN GEORGIA

This chapter presents the pavement service interval, including both Pavement Resurfacing Interval and Pavement 70 Interval, and the distress characteristics using the 370 high-quality resurfacing cycles that were obtained through the data processing procedure described in the previous chapter. The pavement service intervals were analyzed by working district, functional class, AADT category, and year to reveal any difference in the service intervals by these factors. In addition, the Pavement 70 Intervals were mapped to show the spatial distribution with different traffic categories (high, medium, or low). Types of pavement distresses on the pavements correspond to the causes of pavement defects and the treatment method; they are critical for understanding the pavement deterioration behavior. Therefore, analyses were performed on distress data, including type, deduct, and extent, to identify the predominant distresses on Georgia's roads and to understand how they deteriorate over the years. Distress deducts were first studied to reveal how different pavement distresses contribute to the overall pavement rating. The distress distribution in different districts was, also, analyzed to reveal whether or not any specific pavement distresses should be given more attention based on the pavement's geographic locations. It is noted that very few high-quality resurfacing cycles (2) are on interstate highways; thus, the findings based on the 370 resurfacing cycles may not represent the behaviors on the interstate highways. In addition, the findings are not for GDOT's new route priority system (critical, high, medium, and low priority)

4.1 Statewide Pavement Service Interval

The average Pavement Resurfacing Interval of the 370 high-confidence pavement resurfacing cycles is 11.6 years with a standard deviation of 3.4 years, as shown in Figure 4.1. This indicates that, on average, pavements were resurfaced every 11.6 years given the funding level and GDOT's resurfacing practices. The corresponding ratings before resurfacing (RBR) are also plotted in Figure 4.1. Most of the resurfacing cycles have an RBR less than 70 and an average of 64.8; there is no significant difference in the average RBR for different Pavement Resurfacing Intervals. It is noted that the sample sizes are small for the long and short Pavement Resurfacing Intervals; thus, the average RBR for long or short resurfacing cycles may not be representative. Further investigations will be needed to better understand these observations.

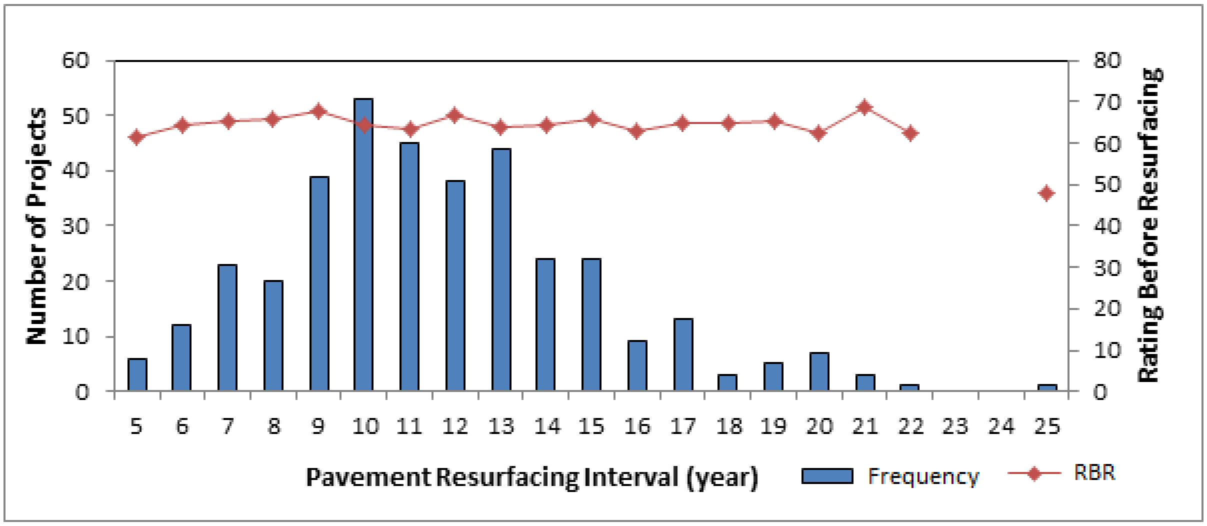


Figure 4.1 Pavement Resurfacing Interval distribution

The Pavement 70 Interval, which provides a consistent measure of pavement resurfacing cycles, is shown in Figure 4.2. The average Pavement 70 Interval of the 370 pavement resurfacing cycles is 10.6 years with a standard deviation of 3.4 years. This indicates that, on average, the pavements reach a rating of 70 (the criteria for resurfacing) in 10.6 years, and 84% of the pavements can last longer than 7 years based on the distribution shown in Figure 4.2.

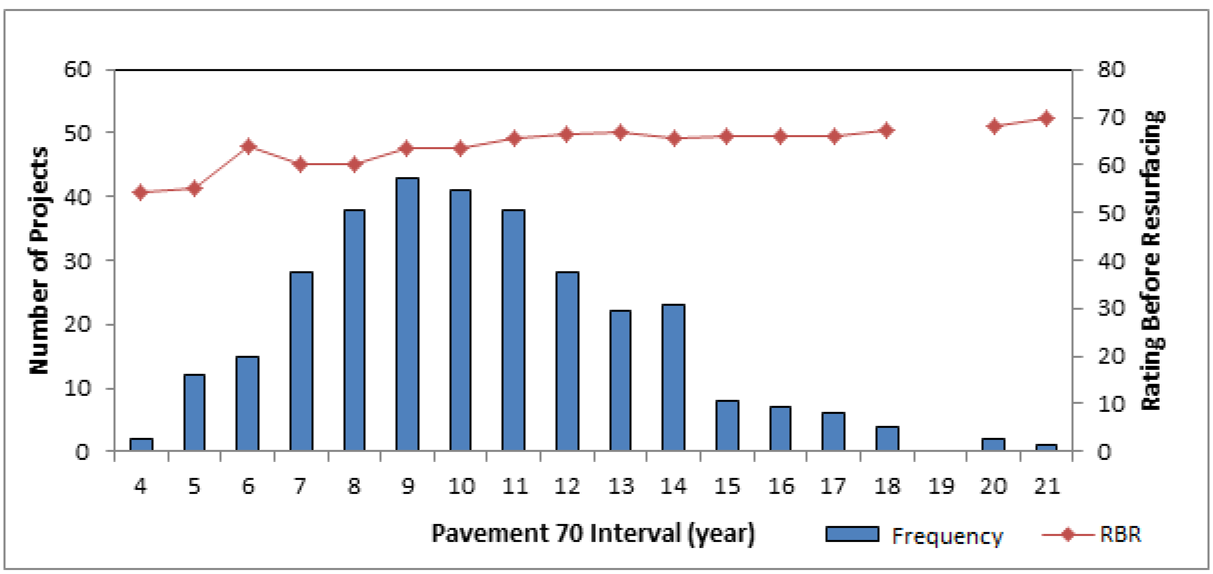


Figure 4.2 Pavement 70 Interval distribution

This finding proves and closely matches GDOT engineers' experience of 10 years as a resurfacing interval, which is used in the life-cycle cost analysis (LCCA). This finding is important in establishing data-driven decision-making in the LCCA analysis of pavement design. The corresponding RBRs in Figure 4.2 show a slightly increasing trend as Pavement 70 Life increases. For the project with longer lives, this may imply that an early resurfacing may prolong the pavement service interval in the following cycles. The Pavement Resurfacing Interval is 0.9 years longer than the Pavement 70 Interval. This indicates resurfacing was applied approximately one year after the resurfacing need was identified (a rating below 70). This matches GDOT's resurfacing program practices described in Chapter 2. It is noted that the distribution of the Pavement 70 Interval, shown in Figure 4.3, has a wide range of 4-21 years. There are some projects with very long and very short Pavement 70 Intervals that warrant an in-depth study of the factors impacting pavement resurfacing performance. Figure 4.3 shows an example of a project with a long Pavement 70 Life, and a rating increase can be observed in 2002. This may be attributed to the pavement preservation activities, such as crack sealing, and can be further studied to identify the practices to cost-effectively extend pavement service intervals.

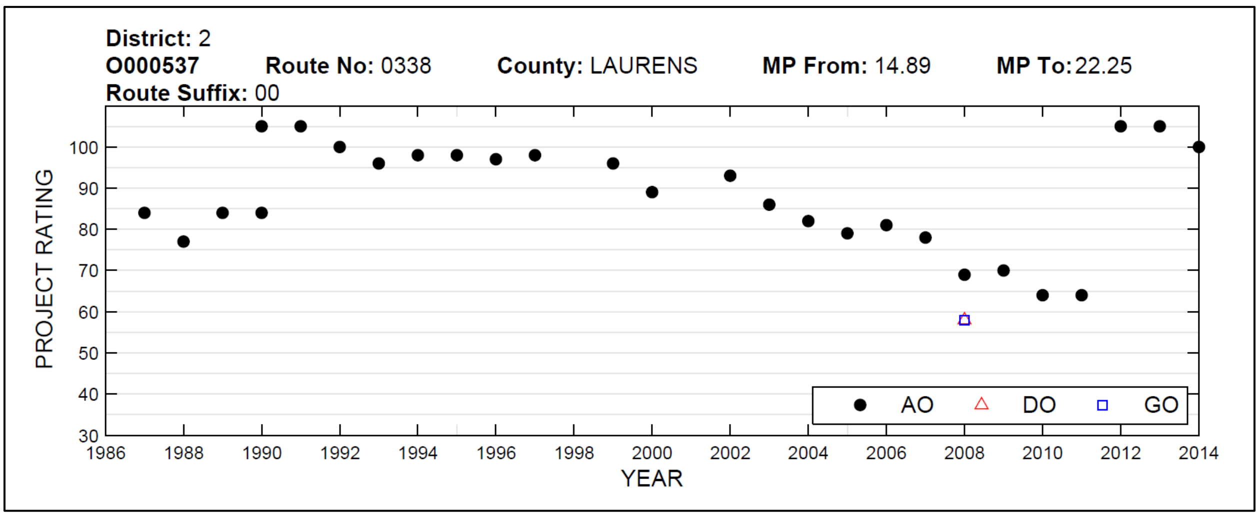


Figure 4.3 Example of project with long Pavement 70 Interval

4.2 Pavement Service Interval by Working District

Pavement resurfacing cycles were categorized by working district to explore differences in pavement service intervals among the seven districts that have varying characteristics (e.g., climate, soil, etc.). Figure 4.4 shows the average Pavement Resurfacing Interval, which ranges from 10.3 to 12.2 years, and associated RBRs in all districts. District 5 has the highest Pavement Resurfacing Interval (12.2 years), while Districts 6 and 7 have lower Pavement Resurfacing Intervals (10.3 years and 10.6 years, respectively). RBRs are fairly close to each other across different working districts (Districts 1-6), ranging from 64.3 to 66.1. District 7 shows a special pattern compared to the rest of the districts; that is, the resurfacing life is among the lowest (i.e., 10.6 years) with a fairly low RBR (i.e., 62.5). This indicates the pavements have a shorter Pavement 70 Interval, as shown in Figure 4.5. This may be attributed to the highly urbanized areas with different traffic patterns within the district.

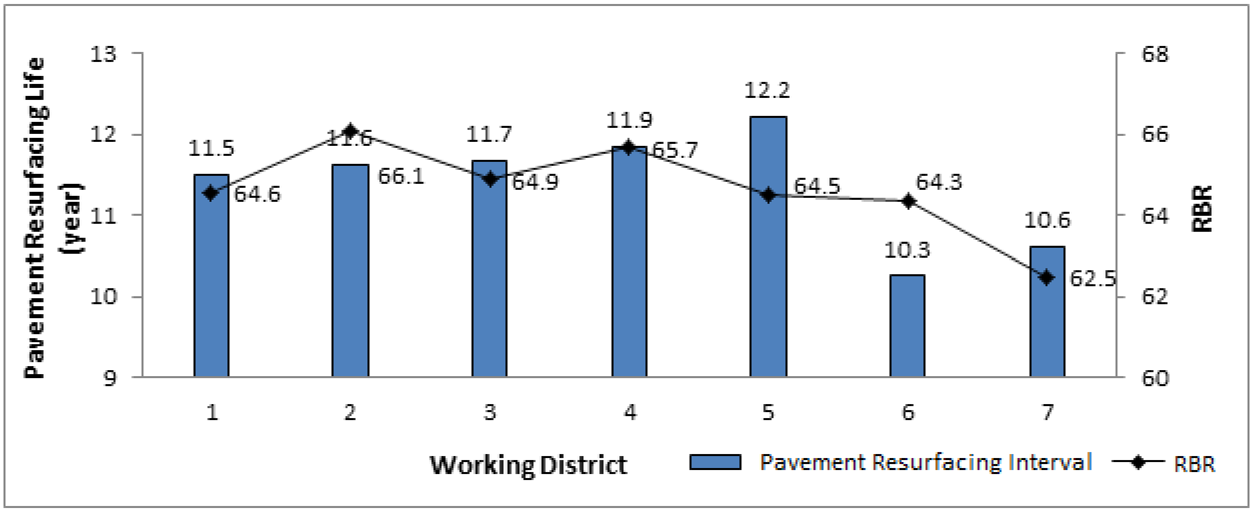


Figure 4.4 Pavement Resurfacing Interval by Working District

Figure 4.5 shows the average Pavement 70 Interval ranges from 9 to 10.8 years with a trend similar to the Pavement Resurfacing Interval. District 5 has the longest Pavement 70 Interval (10.8 years), while Districts 6 and 7 have shorter intervals (9.3 years and 9 years, respectively). Because different working districts have different kinds of soil support, a further investigation was conducted to discover whether the soil support value (SSV) is a factor that subtly affects the average resurfacing life among different districts. The black line in Figure 4.5shows the SSVs across different districts. It can be observed that the average Pavement 70 Interval follows the trend of soil support in the districts. In the AASHTO pavement design method, the SSV is one of the variables (together with estimated total equivalent W18, reliability, etc.) for calculating the Structural Number (SN) for a pavement. After the SN is calculated, the layer coefficient for different materials (e.g., HMA, GAB. etc.) is used to determine pavement layers to achieve a desired SN (sum of aixhi >= SN). Further study is needed to investigate the relationship between the SSV and the pavement service interval.

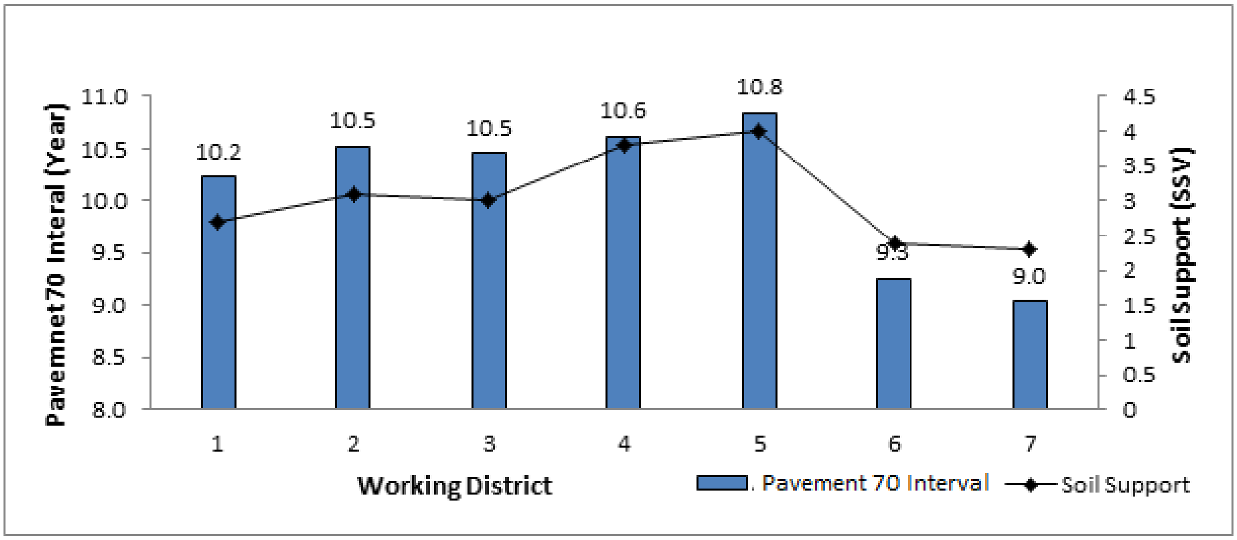


Figure 4.5 Pavement 70 Interval and Soil Support Value (SSV)

4.3 Pavement Service Interval by AADT Category

The pavement service interval is affected by traffic load; therefore, pavement resurfacing cycles are studied based on traffic categories. The AADT is categorized into three levels: ADT>10,000 (High); AADT between 5,000 and 10,000 (Medium) and AADT < 5000 (Low) (Tsai et al., 2005). Figure 4.6 shows an average Pavement Resurfacing Interval of 11.6, 12, and11.2 years for the high, medium, and low traffic categories, respectively. It is noted that there was no significant difference in the RBR for the three traffic categories. This indicates there are only slight differences in how often the pavements were resurfaced in the three traffic categories.

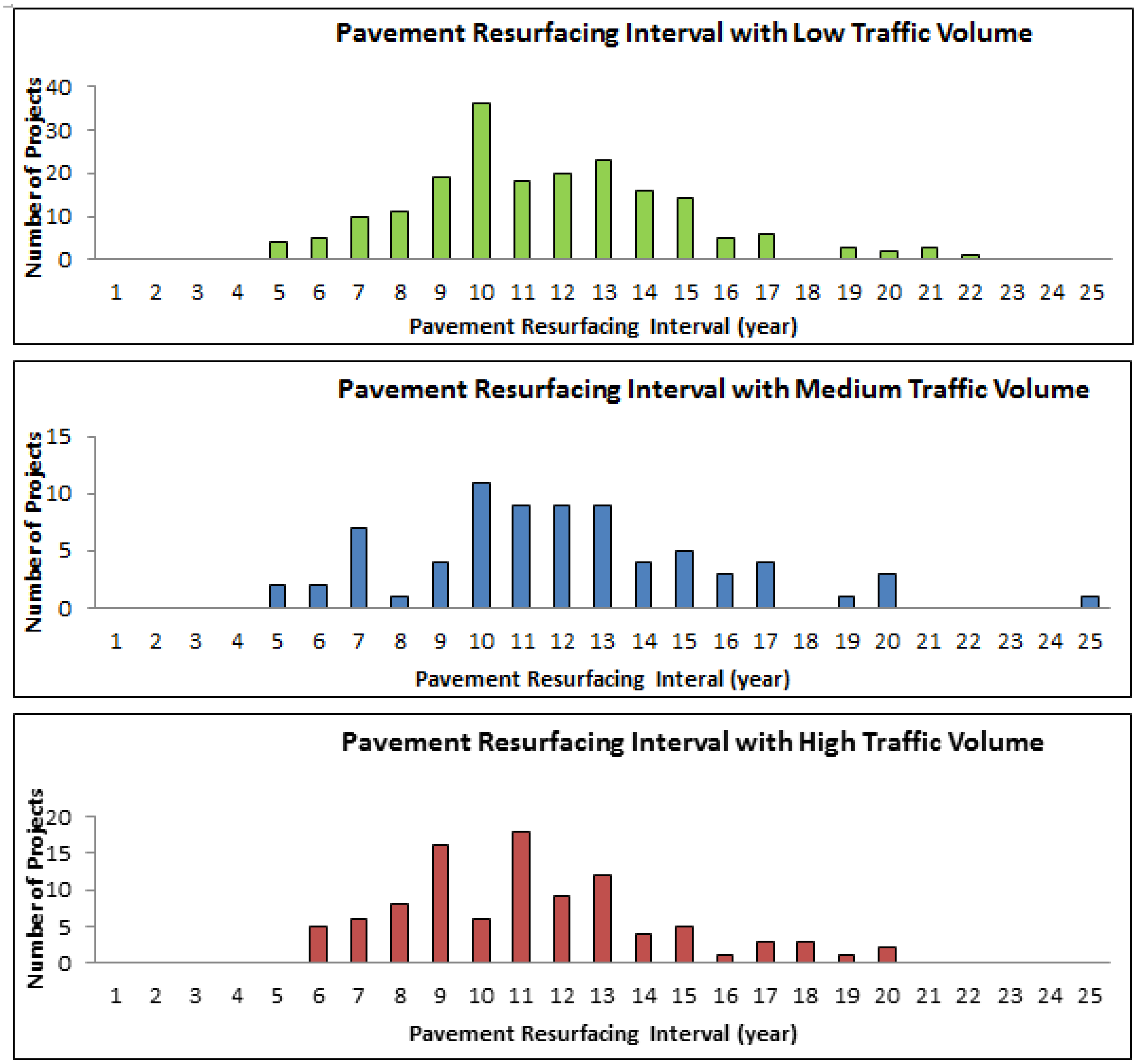


Figure 4.6 Pavement Resurfacing Interval by AADT Category

Figure 4.7 shows that the pavements with high, medium, and low traffic have an average Pavement 70 Interval of 10.4, 10.7, and 9.8 years, respectively. Intuitively, one would expect the pavements with high traffic to have a shorter pavement service interval than the pavements with medium and low traffic because the pavement bearing the high traffic volume is more likely to deteriorate faster when the pavements have similar designs. As shown in Figure 4.7, the pavements with medium traffic have a slightly longer Pavement 70 Interval than the pavements with high traffic, but this trend is not present in the pavements with low and medium traffic. This could be because a better pavement design has been applied to the pavements with a higher traffic volume. Thus, further in-depth study is needed to better understand the relationship between pavement service interval and traffic volume.

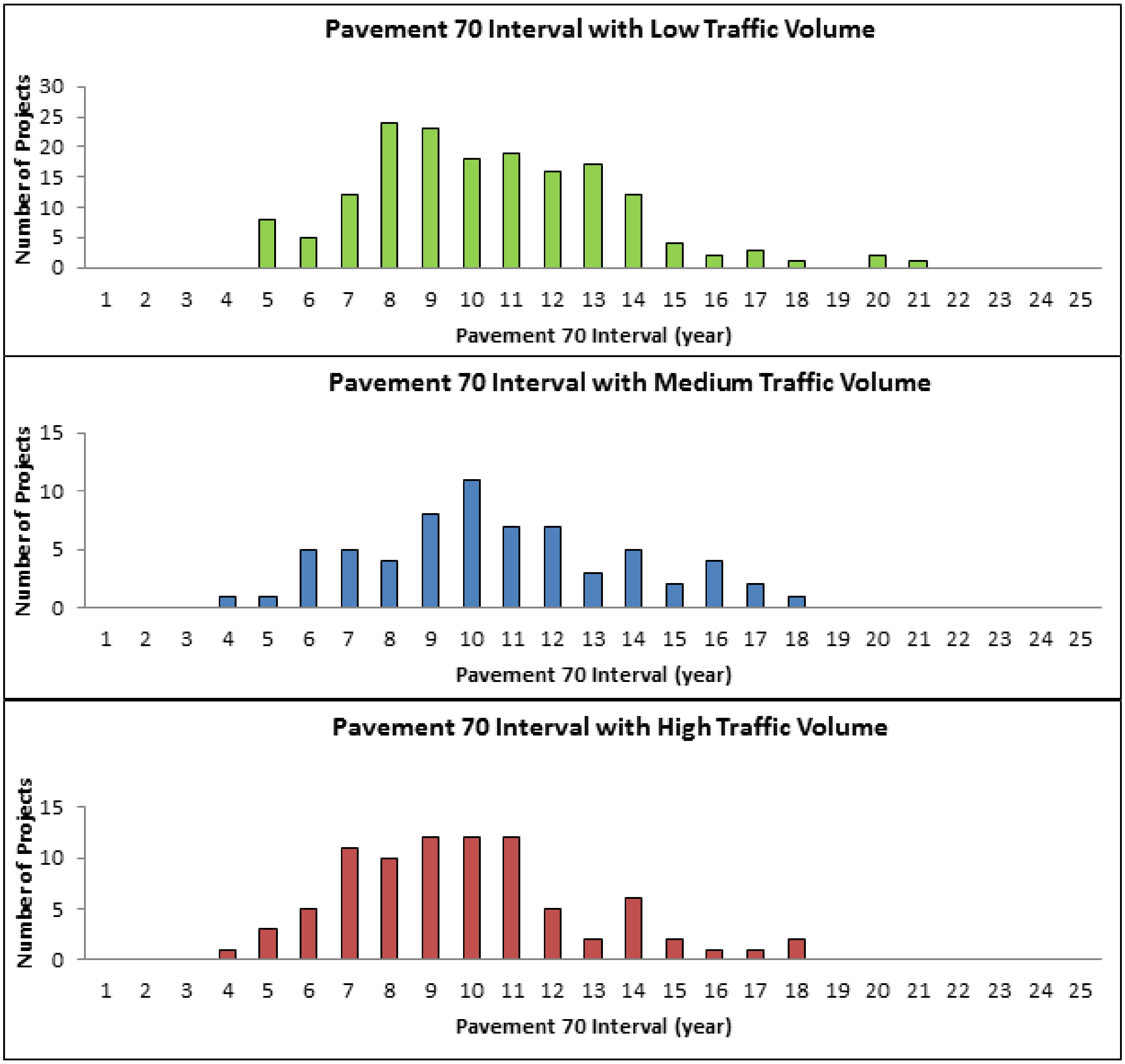


Figure 4.7 Pavement 70 Interval by AADT Category

4.4 Pavement Service Interval by Function Class

Functional classes are defined as the groups of roads based on the level of services they provide. GDOT's functional classes are defined in Table 4.1. The importance of Functional Class in the analysis cannot be overstated, since the selection of the pavement design may have been based on Functional Class. The design of the pavement, in turn, influences the service interval of the pavement. To reveal whether the pavement service intervals vary among different functional classes could help GDOT carry out a more balanced and prioritized maintenance strategy.

Table 4.1 List of Functional Classes

FC 01 Principal Arterial – Interstate (Rural)
FC 02 Principal Arterial – Other (Rural)
FC 06 Minor Arterial (Rural)
FC 07 Major Collector (Rural)
FC 11 Principal Arterial – Interstate (Urban)
FC 12 Principal Arterial.- Other Frwy/Expressway (Urban)
FC 14 Principal Arterial – Other (Urban)
FC 16 Minor Arterial (Urban)
FC 17 Collector (Urban)

Figure 4.8 shows the Pavement Resurfacing Intervals across different functional classes. It should be noted that there are very limited projects for functional classes FC01, FC07 and FC11. Overall, it can be observed that all functional classes have an average Pavement Resurfacing Interval of greater than 10 years, except FC07 (8 years). In addition, the average Pavement Resurfacing Interval in the urban area (11.9 years) is approximately one year longer than in the rural area (10.8 years). It is noted that the pavement design in rural and urban areas can be different because of the traffic loads.

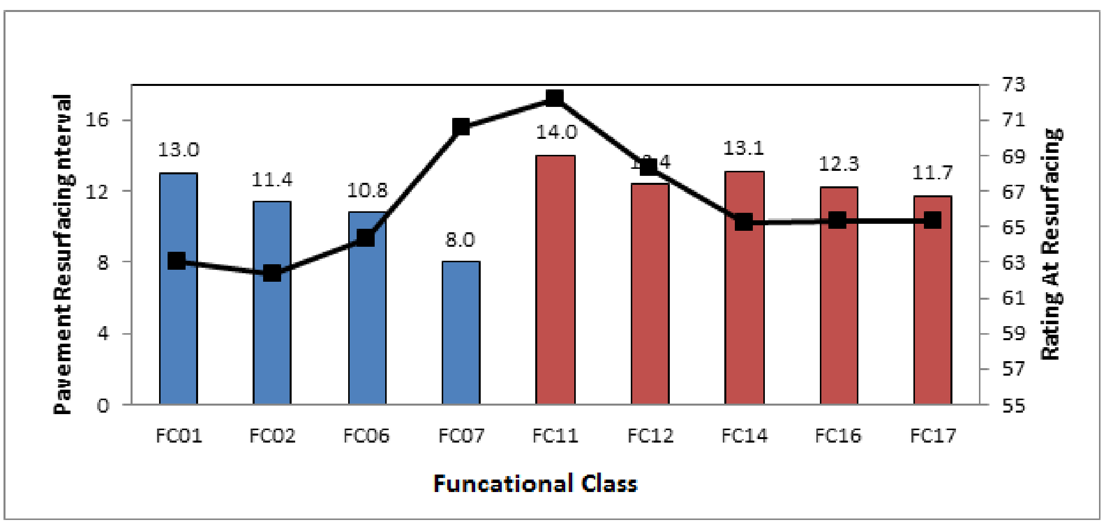


Figure 4.8 Pavement Resurfacing Interval by Functional Class

Figure 4.9 shows the Pavement 70 Interval by functional class. The Pavement 70 Interval shows a trend similar to the Pavement Resurfacing Interval with longer service intervals in the urban areas. The only difference is in FC12, where Pavement 70 Interval shows a significant short RBR compared to the resurfacing service interval. This is due to the limited number of samples for this functional class.

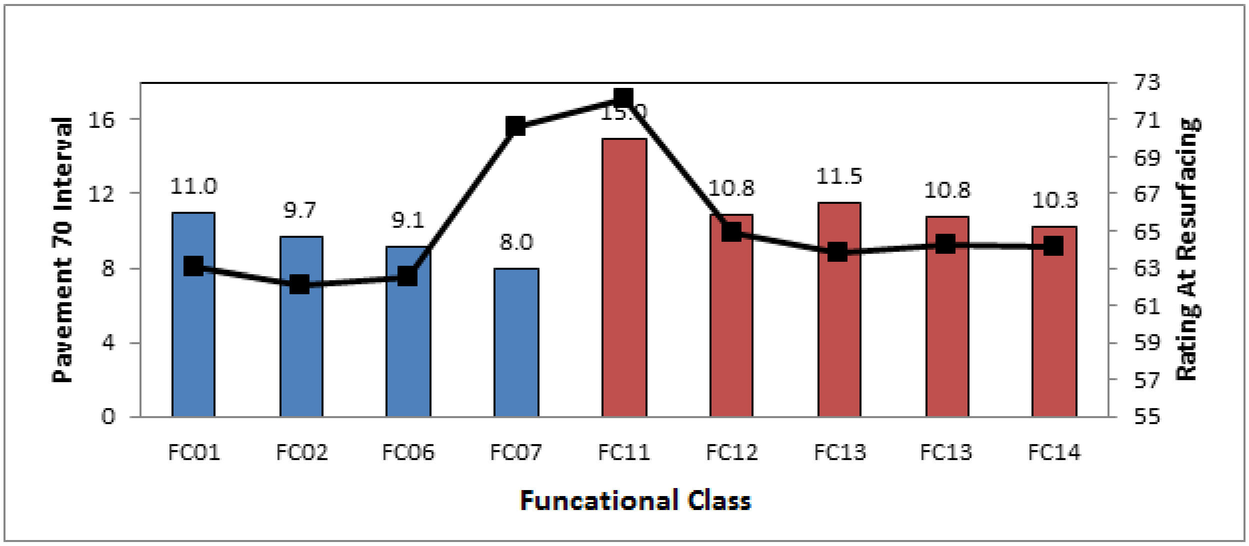


Figure 4.9 Pavement 70 Interval by Functional Class

4.5 Pavement Service Interval by Year

Over the years, GDOT has adapted new materials, construction methods, etc., to enhance its resurfacing practices. Therefore, the pavement life is studied based on the year that the resurfacing was applied, which is the start year. Figure 4.10 shows the average Pavement 70 Interval by the start year of the pavement resurfacing cycle. It is noted that the start year is limited to between 1987 and 2002; the Pavement 70 Interval after 2002 can be biased because only the projects with short service intervals are available. The average Pavement 70 Interval is approximately 10 years in 1987 and 1988. The average life increases to approximately 12 years between 1989 and 1998, which may indicate improvement in the pavement design, mix design, and/or construction. The Pavement 70 Interval decreases to 11 years between 1999 and 2002.

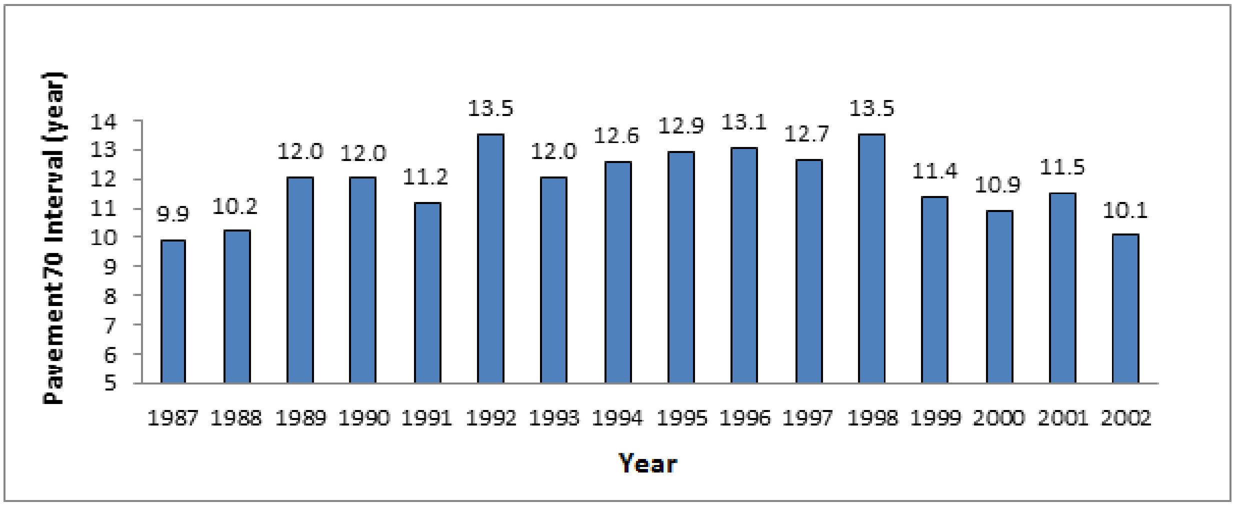


Figure 4.10 Average Pavement 70 Interval by Year

4.6 Spatial Distribution of Pavement 70 Interval

GIS is an intuitive way to display spatial data. In this section, the projects categorized by life and traffic (AADT) are plotted on the GIS Base Map with State Boundary, District Boundary, and Road Network, as shown in Figure 4.11. The map shows the location of the projects along with Pavement 70 Interval, which is categorized into Short Interval (0 -7 years), Medium Interval (8 – 13 years) and Long Interval (14 – 20 years), in different colors. Traffic category is represented by the thickness of the line, as shown in Figure 4.11. With the statewide mapping application in place, the distribution of the pavement service interval within the districts and the state can be visualized. Also, the location of projects with extremely short or long service intervals can be studied. Likewise, with the expansion of the GIS database, it is easy to see how other causative variables can be studied in future research. In Figure 4.11, note the scattered distribution of long service intervals and high AADT pavements. With the lack of pavement service intervals in many areas, it is important to improve the data collection quality in the future. In the meantime, further research is needed to recover those medium-quality projects. With these efforts, the increased number of high-quality projects in conjunction with GIS functionality can be used to analyze and understand the pavement behavior and deterioration.

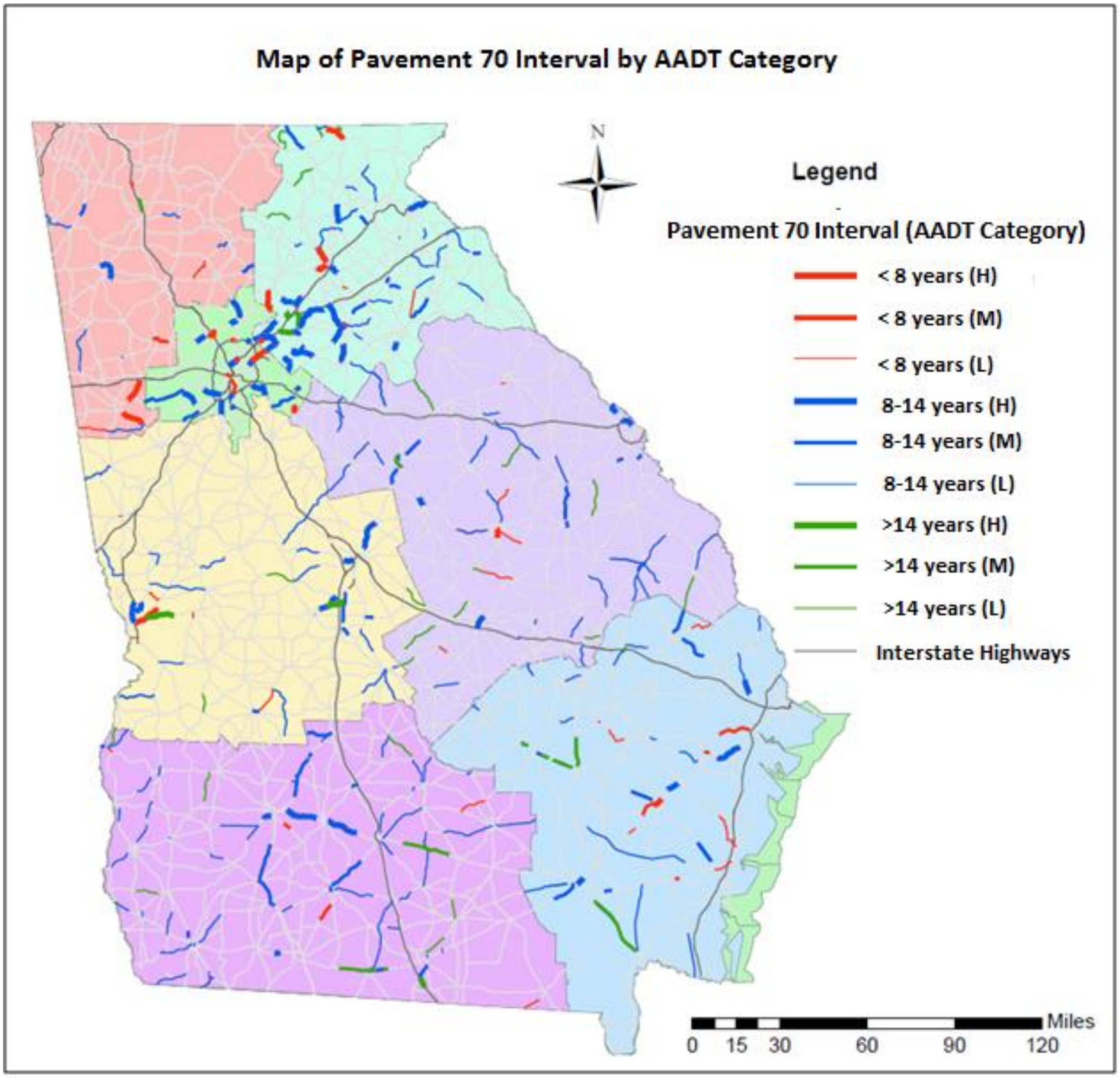


Figure 4.11 Map of Pavement 70 Interval

4.7 Predominant Distresses

Distress deducts of the 370 high-quality pavement resurfacing cycles were analyzed to better understand the predominant pavement distresses in Georgia. The average distress deduct is obtained by computing a length-weighted average over the distress deducts of all analyzed cycles. The average deduct value and percentage of each distress contributing to the total pavement deducts are shown in Figure 4.12. The three predominant pavement distresses, load cracking, block cracking, and rutting, account for 90% of the total deducts. Load cracking accounts for approximately 46.7% of the total deducts, followed by block cracking (35.1%) and rutting (8.6%). It is noted that block cracking may also include reflective cracking when the surveyor does not have the information on the underlying pavement type (i.e., concrete pavement). The average rutting deduct is 2.9, which corresponds to an average rut depth of less than ¼ inch. This indicates, in general, that rutting is not a major concern on the pavements. Rutting was once an issue in Georgia in the mid-1990s (Brown & Brownfield, 1988). After applying new pavement materials and structural designs, rutting is now not an issue.

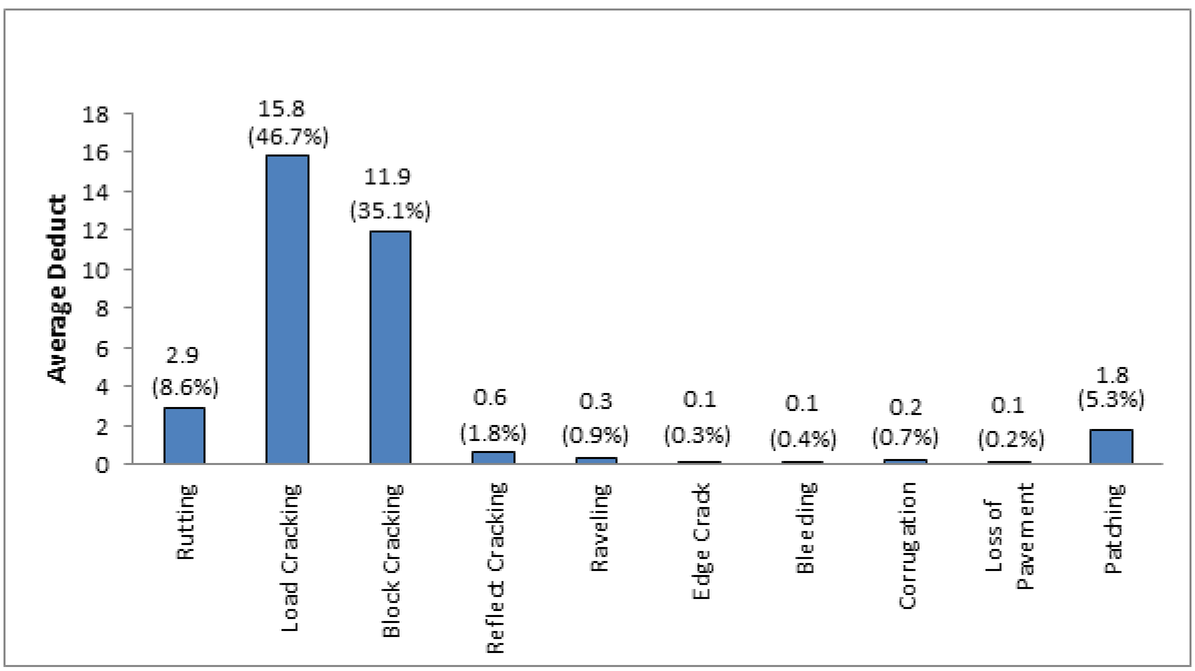


Figure 4.12 Deducts by distress type

The distress deducts were further studied by working districts to explore the differences in distresses in the seven districts. Figure 4.13 shows the percentage of each distress contributing to the total pavement deducts by working district. Load cracking, block cracking, and rutting remain the predominant distresses among all districts. Load cracking accounts for the most of deducts in all districts, ranging from 42% to 53.8%; it is followed by block cracking, ranging from 25.5% to 39.1%. A further review reveals that the block cracking accounts for a higher percentage (37.4%-39.1%) in the southern region (i.e., Districts 2, 4, and 5) than that the northern region (i.e., 25.5%-32.0% in Districts 1, 6, and 7). This may be because of the underlying concrete pavement, base type (e.g., soil cement treated base), soil type, etc.

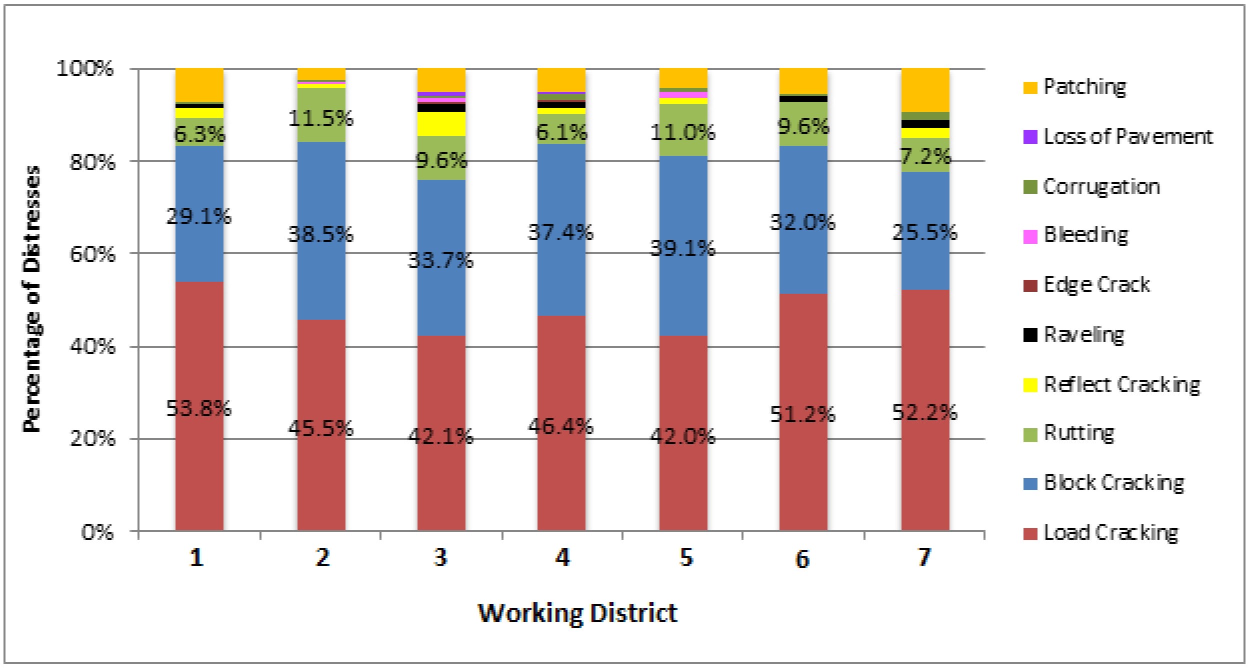


Figure 4.13 Deduct by Working District

4.8 Distress Deterioration on Selected Resurfacing Cycles

To further understand the pavement deterioration behavior, a preliminary study was conducted using 32 selected resurfacing cycles to gain an understanding of how the distresses began and deteriorated within the pavement resurfacing cycle. These cycles were selected from the 370 high-quality with a typical Pavement Resurfacing Interval (i.e., 12 years). Figure 4.14 shows the trend of distress deterioration for all distresses by averaging the deducts in each year.

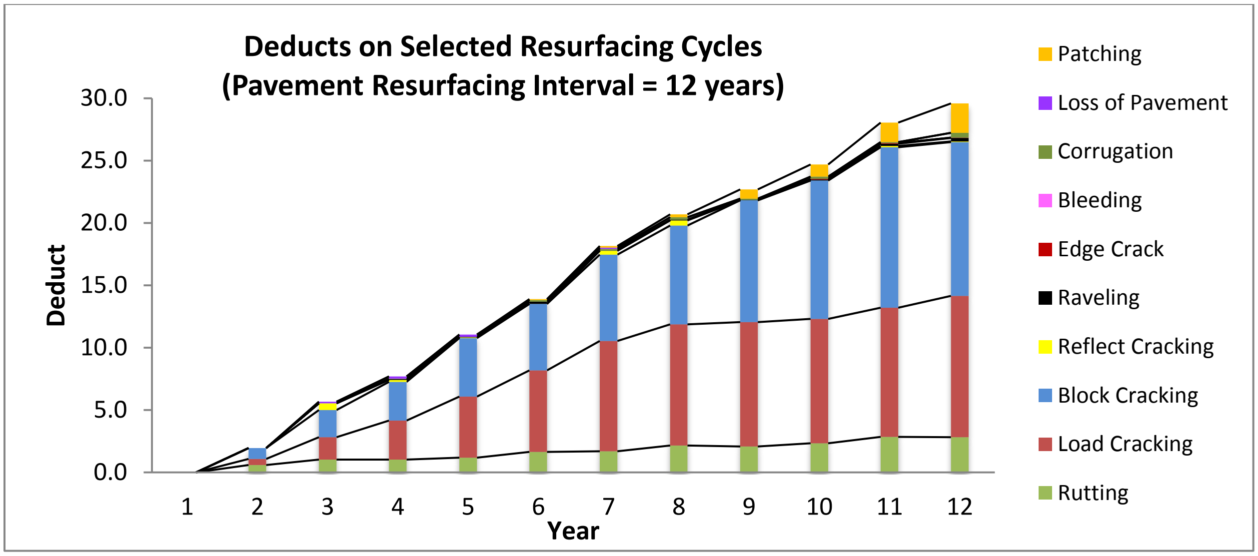


Figure 4.14 Deducts on selected resurfacing cycles (Pavement Resurfacing Interval = 12 years)

It can be observed that the load cracking, block cracking, and rutting are consistently the predominate distresses throughout the pavement resurfacing cycle. It is noted that these three distresses, load cracking, block cracking, and rutting, were reported very early in the 2nd year of the pavement resurfacing cycle. Load cracking and block cracking were reported with a low deduct (e.g., less than 1) in the 2nd year. This may indicate the distresses were observed on only a few projects or segments; thus, the average deducts are very low. An early observation of load cracking and/or block cracking on a newly resurfaced pavement might imply issues in the underlying layer or propagation of cracks on the milled surface. Load cracking deducts reach 5 points in 5th year. It continues to deteriorate at a rate of 2 points per year until the 8th year and remains flat after the 8th year. Block cracking deducts increase linearly at the rate of 1.3 points per year until the end of pavement life. Rutting deducts were reported in the 2nd year and show a relatively small increase over the years. Some of the other distresses developed but remained at a minimal percentage. However, potholes/patches became more common toward the end of the pavement resurfacing cycle (e.g., after 10 years), as a significant amount of material is missing due to the severe and nested cracking. A statewide pavement deterioration study based on GDOT four state prioritization categories (critical, high, medium and low) is recommended to get a complete understanding of pavement deterioration in Georgia to support GDOT's new policy.

5 ASSESSMENT OF PAVEMENT RESURFACING DELAY CONDITION

This chapter presents the pavement resurfacing delay condition by analyzing the rating before resurfacing (RBR), composite rating, and pavement condition in FY2014 to get insight into and understanding of GDOT's resurfacing practices, especially the resurfacing delay situation in the past and present.

5.1 Study of Rating Before Resurfacing (RBR)

A rating of 70 is targeted to trigger resurfacing. However, due to resurfacing delays, the actual RBR could be lower than the target value (a rating of 70). Therefore, a study of the RBR was performed to quantitatively assess the pavement resurfacing delay condition based on actual data. Figure 5.1 shows the difference between the Pavement Resurfacing Interval and the Pavement 70 Interval based on the 370 high-quality pavement resurfacing cycles. This difference indicates the resurfacing delay in years. A one-year difference is considered as no delay because the pavement would be resurfaced within one year after its rating dropped to 70. As shown in Figure 5.1, 49% of the 370 high-quality pavement resurfacing cycles were resurfaced on schedule (i.e., with one-year difference); more than 51% of the projects were not resurfaced at the expected (or right) time. This delay could have been caused by resurfacing programming and bidding processes and/or funding shortages. It is noted that approximately 8% of the resurfacing cycles were delayed for more than three years.

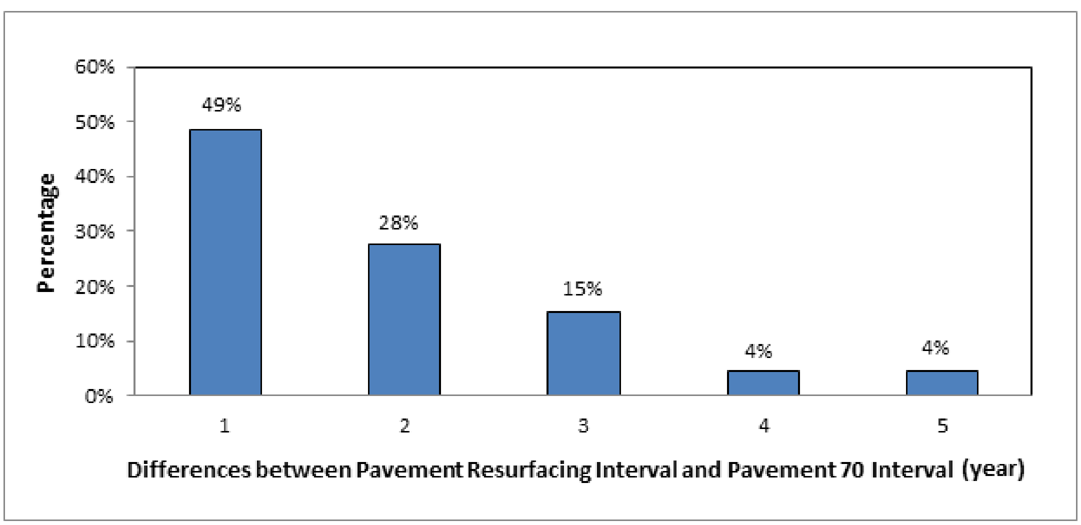


Figure 5.1 Differences between Pavement Resurfacing Interval and Pavement 70 Interval

Figure 5.2 shows the distribution of the RBRs for the 370 high-quality pavement resurfacing cycles; approximately 7% of the resurfacing was performed at a rating of 55 or below. Funding shortages could be the reason for the long delay, and this is a serious problem GDOT and other state DOTs face. Pavements would deteriorate faster and require more expensive treatment (e.g., deep patching and resurfacing) if the resurfacing were not applied in a timely manner.

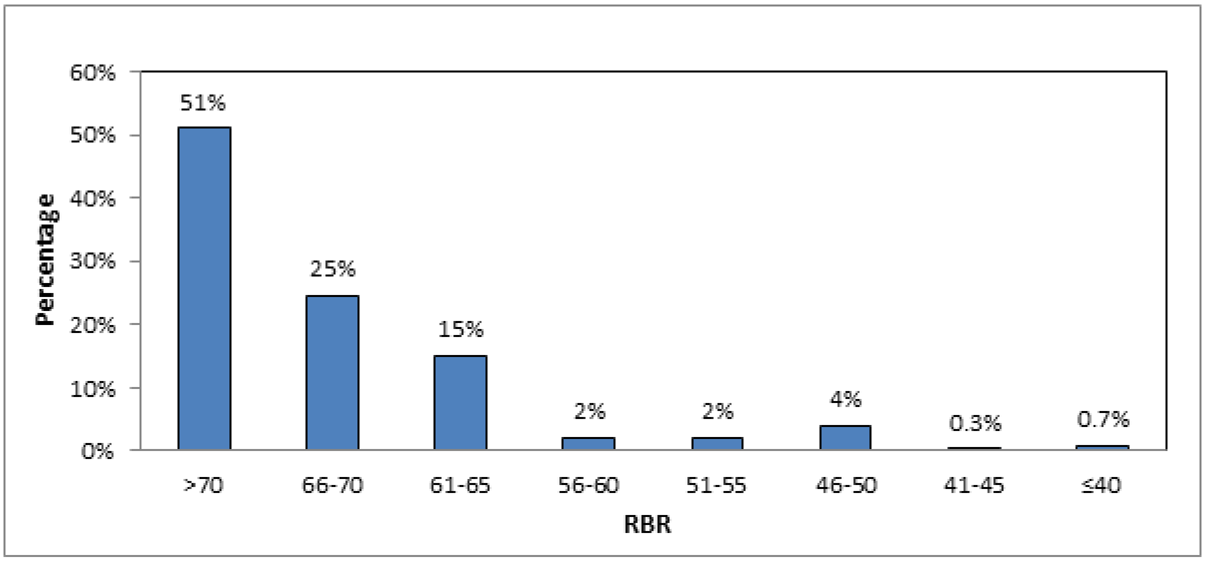


Figure 5.2 Distribution of RBR

Figure 5.3 shows the RBR by fiscal year. The RBR was not available in FY 2001 because of no COPACES survey. It can be observed that the average RBR continues to drop in recent years from 68.8 in FY 2004 to 59 in FY 2012, although this is based on only the 370 high-quality pavement resurfacing cycles. This indicates that the resurfacing has been delayed and the situation has become more severe in recent years. An RBR of 59 in FY 2012 is due to some of the low ratings (in 30s) of some projects. This implies the delayed condition has intensified in recent years with some projects being delayed for several years and resulting in low RBRs. The high RBRs, 73.7 in FY 1996 and 77.6 in FY 1998, need to be further investigated.

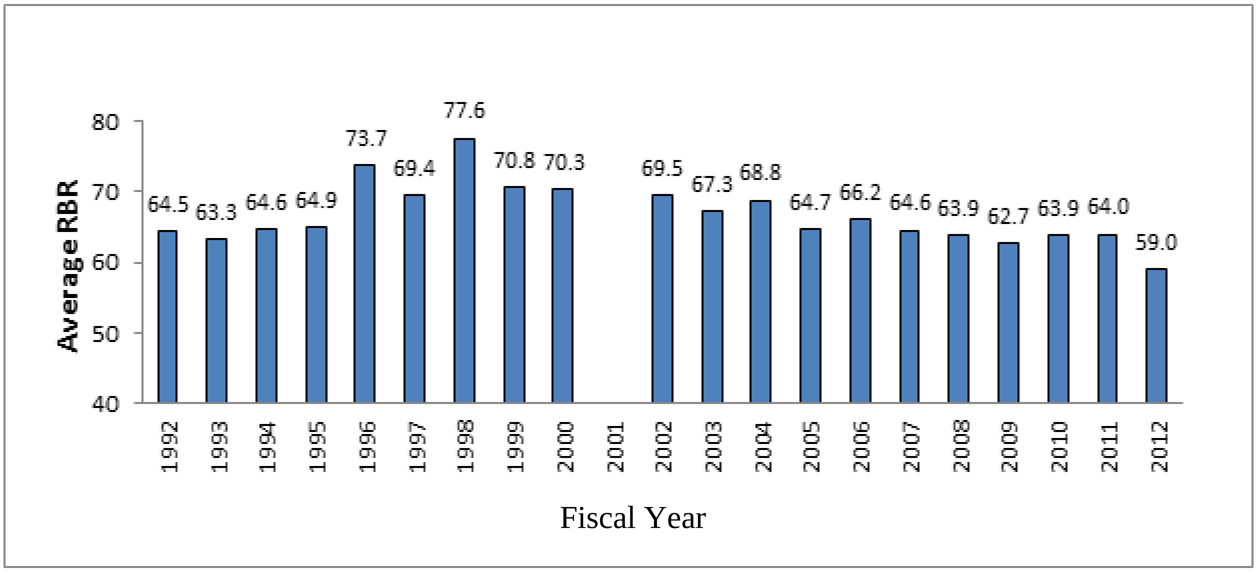


Figure 5.3 RBR by fiscal year

5.2 Composite Rating at the Network Level

Composite rating, a length-weighted rating based on all surveyed projects in one fiscal year, is one of the performance measures for the pavements at the network level. The composite ratings from FY 1986 to FY 2014 were studied to get an insight into and understanding of the change of the pavement condition at the network-level over the years. Figure 5.4 shows the composite rating from FY 1986 to FY 2014. It is noted that the composite rating was computed using only the projects surveyed by the Area Offices to avoid duplicate surveys by more than one office, and an under-construction project is considered as having a rating of 100. There is no composite rating shown in FY 1986, FY 1998, or FY 2001 due to no or limited surveys being conducted in those years. The composite rating decreased steadily (86 to 82) from FY 1989 to FY 1994; it had an increasing trend between FY 1995 and FY 2000. This improvement in the composite rating could be because of the extensive investment in the roadways for the 1996 Summer Olympics and the improvements in the mix design, materials, construction, etc. over the years. The significant increase of composite rating in FY 1999 can be a result of including the under-construction projects, which has a rating of 100. Under-construction projects have only been recorded since the implementation of COPACES in FY 1999. The most distinct trend in Figure 5.4 is the consistent and rapid decline in the composite rating since 2002. It dropped from 88.4

in FY2002 to 79.8 in FY 2014; the composite has been less than 85, a target at the network-level, since 2007.

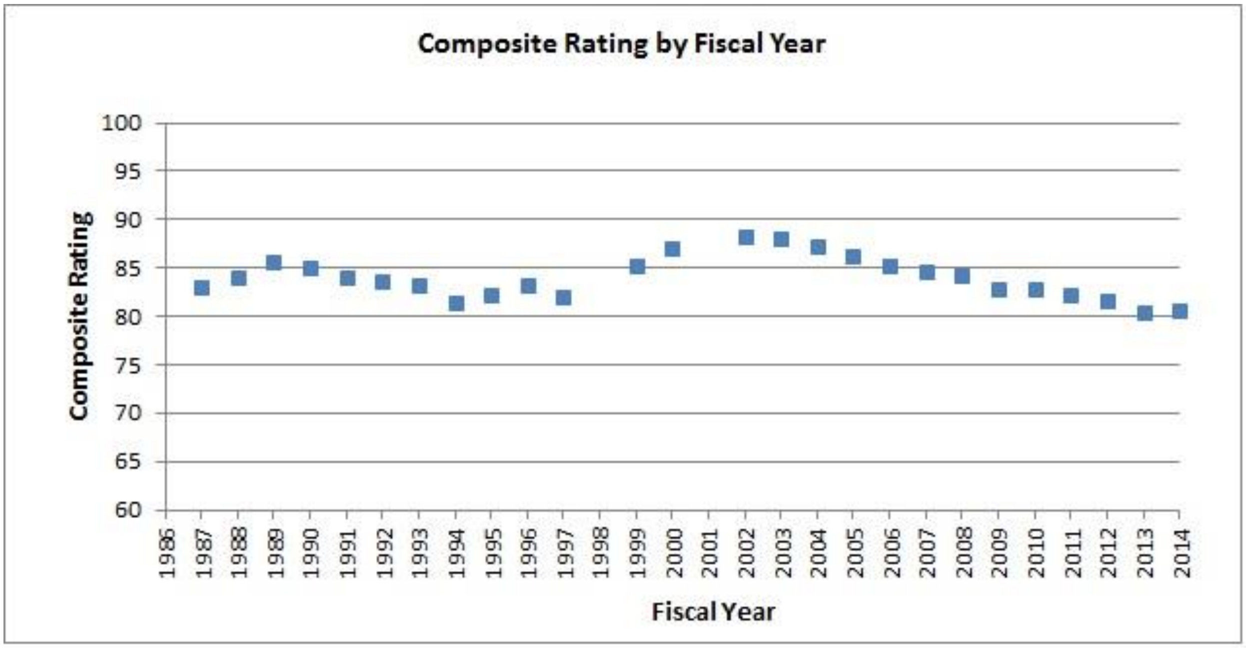


Figure 5.4 Composite rating by fiscal year

This trend corresponds to the decrease in the resurfacing funding, which leads to the increase in the pavement resurfacing delay, as shown in Figure 5.5. The pavements in Poor and Bad conditions have increased by more than 2% per year since 2003. The percentage of pavements with a rating less than or equal to 70 increased significantly from 10% to 19% to 26% in 2000, 2010, and 2014, respectively. It is noted that approximately 5% of the pavements are in bad condition with a rating < 55 in 2014. These pavements may require more expensive treatment (e.g., rehabilitation) or additional treatment (e.g., deep patching) before resurfacing.

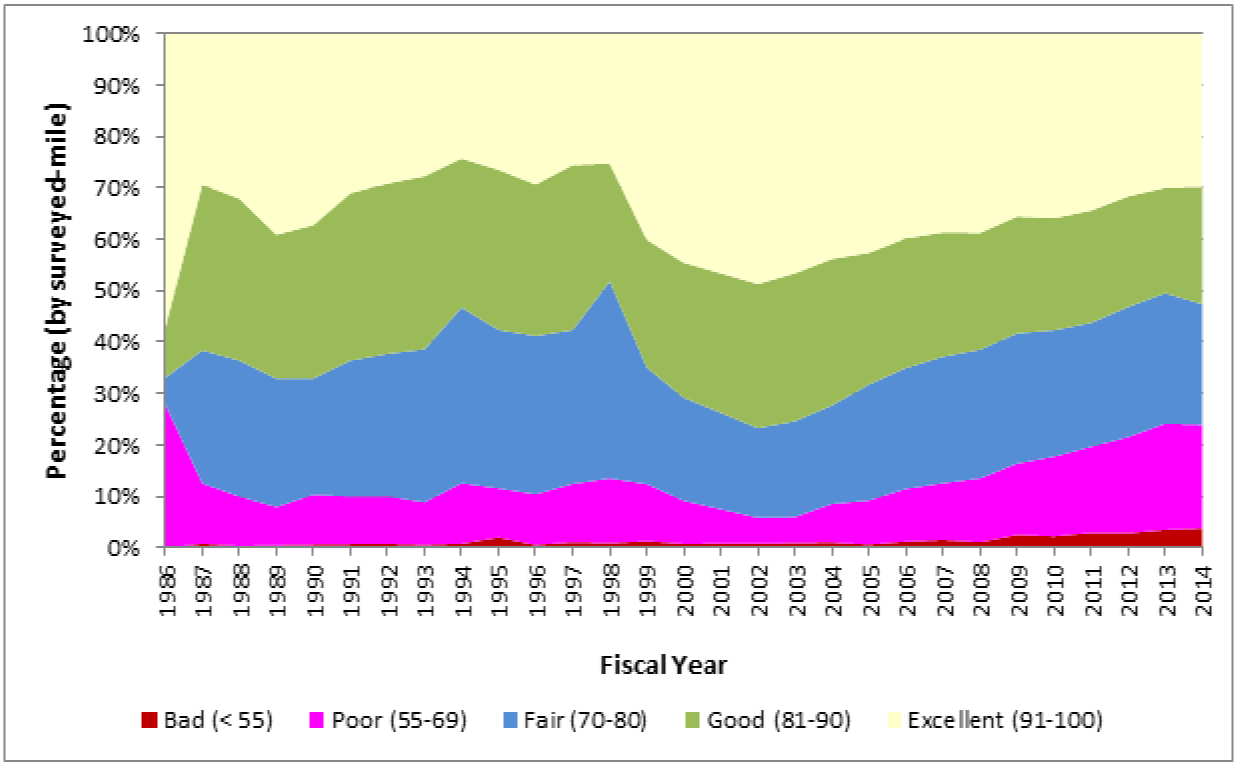


Figure 5.5 Rating distribution by fiscal year

5.3 Resurfacing Delay Condition in FY 2014

The pavement condition in FY 2014 is presented in this section to provide an assessment of the magnitude of the resurfacing delay condition. The pavement resurfacing delay is represented using the total surveyed-miles of roadways that are considered due or past due for resurfacing, i.e., with a rating less than 70. A total of 19,616 miles of roadways were surveyed in FY 2014 with a composite rating of 79.9. It is noted that there was no data in five counties (Dooly, Houston, Macon, Peach, and Pulaski) in District 3. Figure 5.1summarizes the resurfacing delay condition. Approximately 25% (4,691 surveyed-miles) of roadways were due or past due for resurfacing (i.e., having a rating less than 70). Among them, 139 surveyed-miles are on interstates and 4,552 surveyed-miles are on non-interstates.

Table 5.1 Delayed Resurfacing in FY 2014

	District	1	2	3	4	5	6	7	Sub Total
Interstate Highways	<70		12			13	64	50	139
	>=70	154	41	229	149	194	167	218	1152
Non-Interstate Highways	<70	433	800	923	1174	609	292	332	4552
	>= 70	1978	2643	1975	2752	2147	1722	555	13773
All Routes	<70	433	811	923	1174	623	346	382	4691
	>= 70	2132	2684	2204	2901	2341	1890	773	14925
	Total	**2565**	**3496**	**3127**	**4075**	**2964**	**2235**	**1155**	**19616**

Figure 5.6 shows the resurfacing delay on Interstates and non-Interstates in each working district. District 4 has the largest overall resurfacing delay of 1,174 out of total 4,075 surveyed-miles. Districts 6 and 7 have the largest resurfacing delay of 64 and 50 surveyed-miles on interstates; District 4 has the largest resurfacing delay of 1, 174 surveyed miles on non-interstate highways. The percentage of each rating category for interstate and non-interstate is shown in Figure 5.7. Figure 5.8 shows the rating of the surveyed projects in FY 2014. The projects in Bad condition with a rating less than 55 are shown in red. Figure 5.9– 5.15 show the maps for each district.

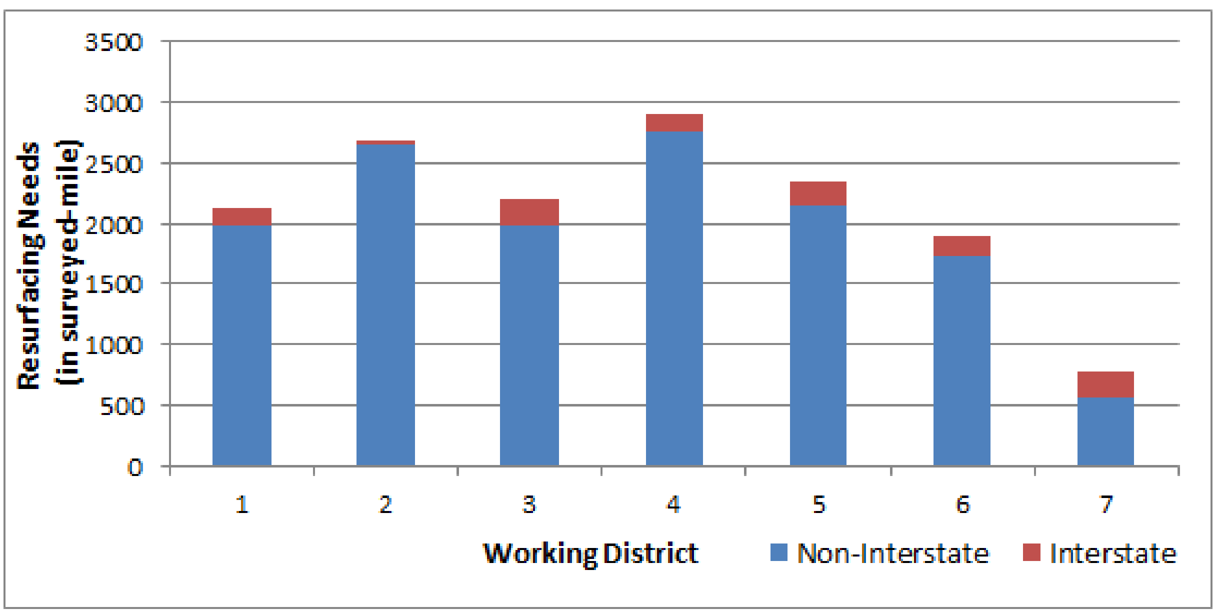
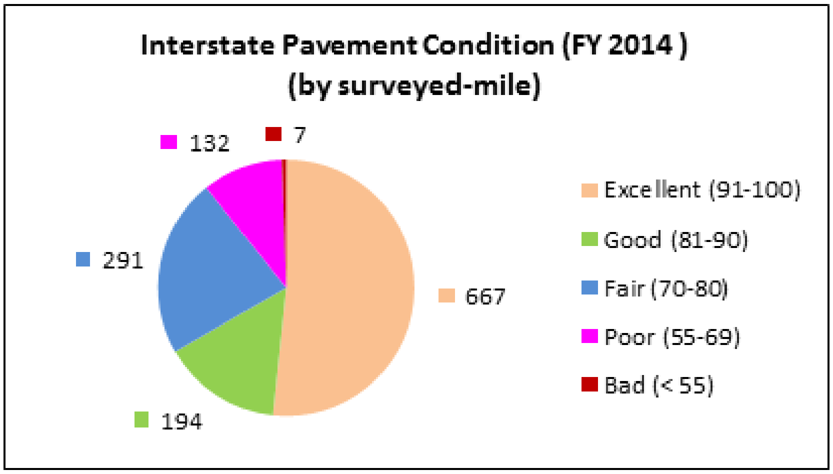


Figure 5.6 Resurfacing needs by working district in FY 2014



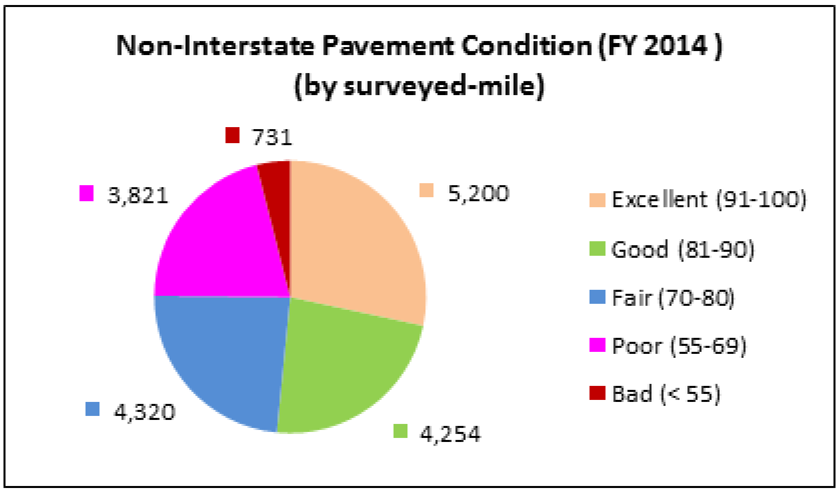


Figure 5.7 Rating distributions for Interstate and Non-Interstate in FY 2014

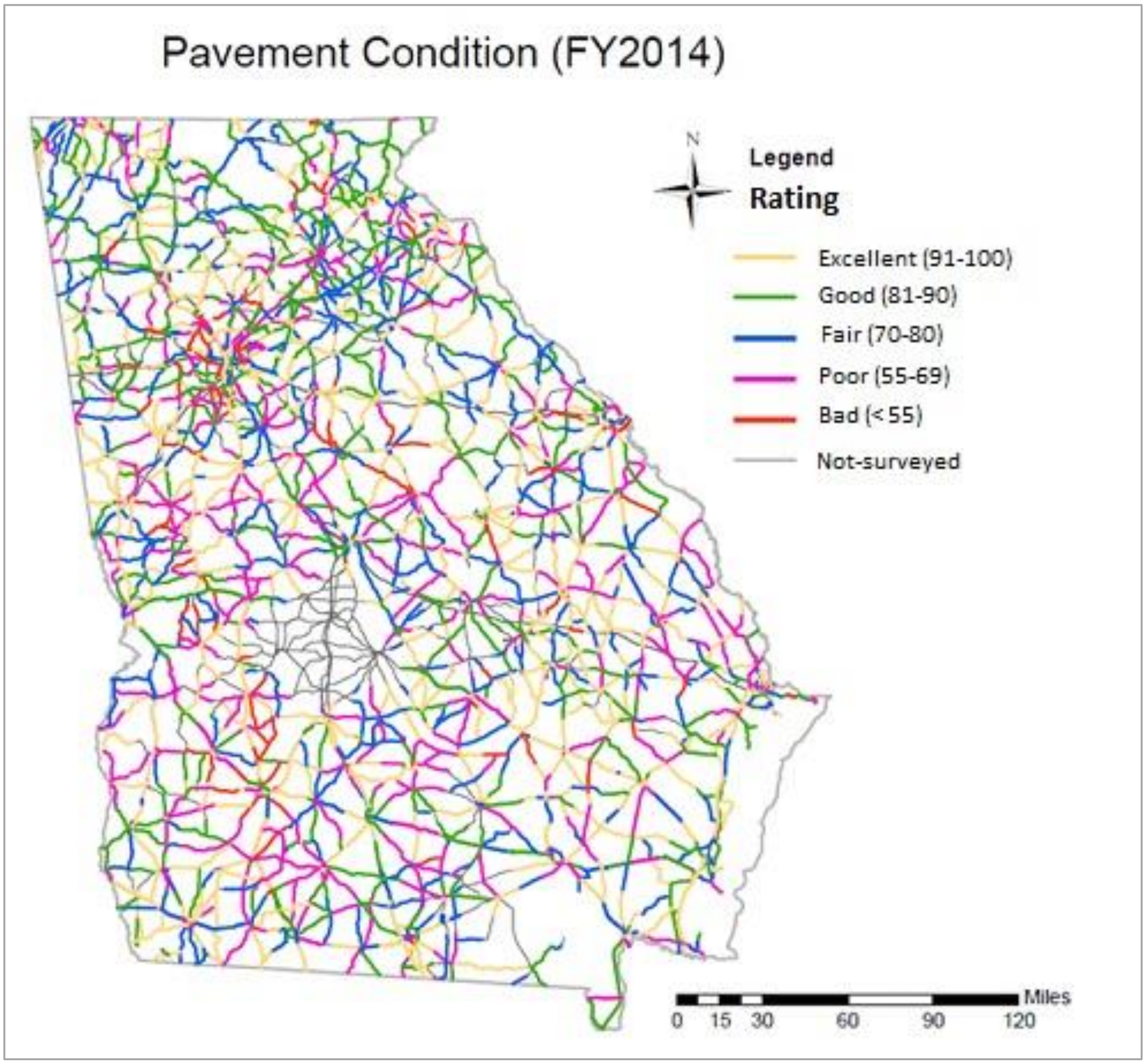


Figure 5.8 Pavement condition in FY 2014

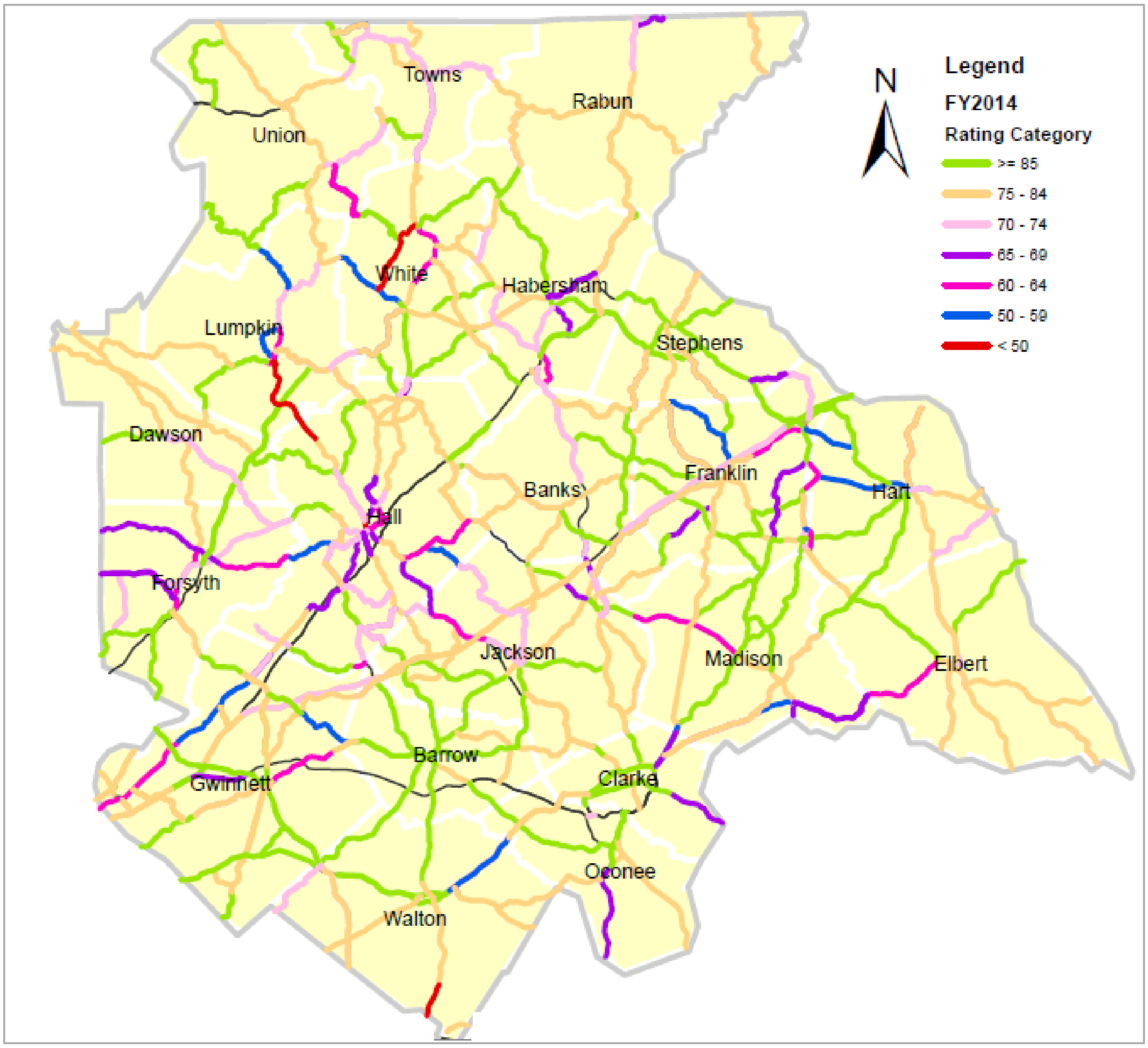


Figure 5.9 District 1 pavement condition in FY 2014

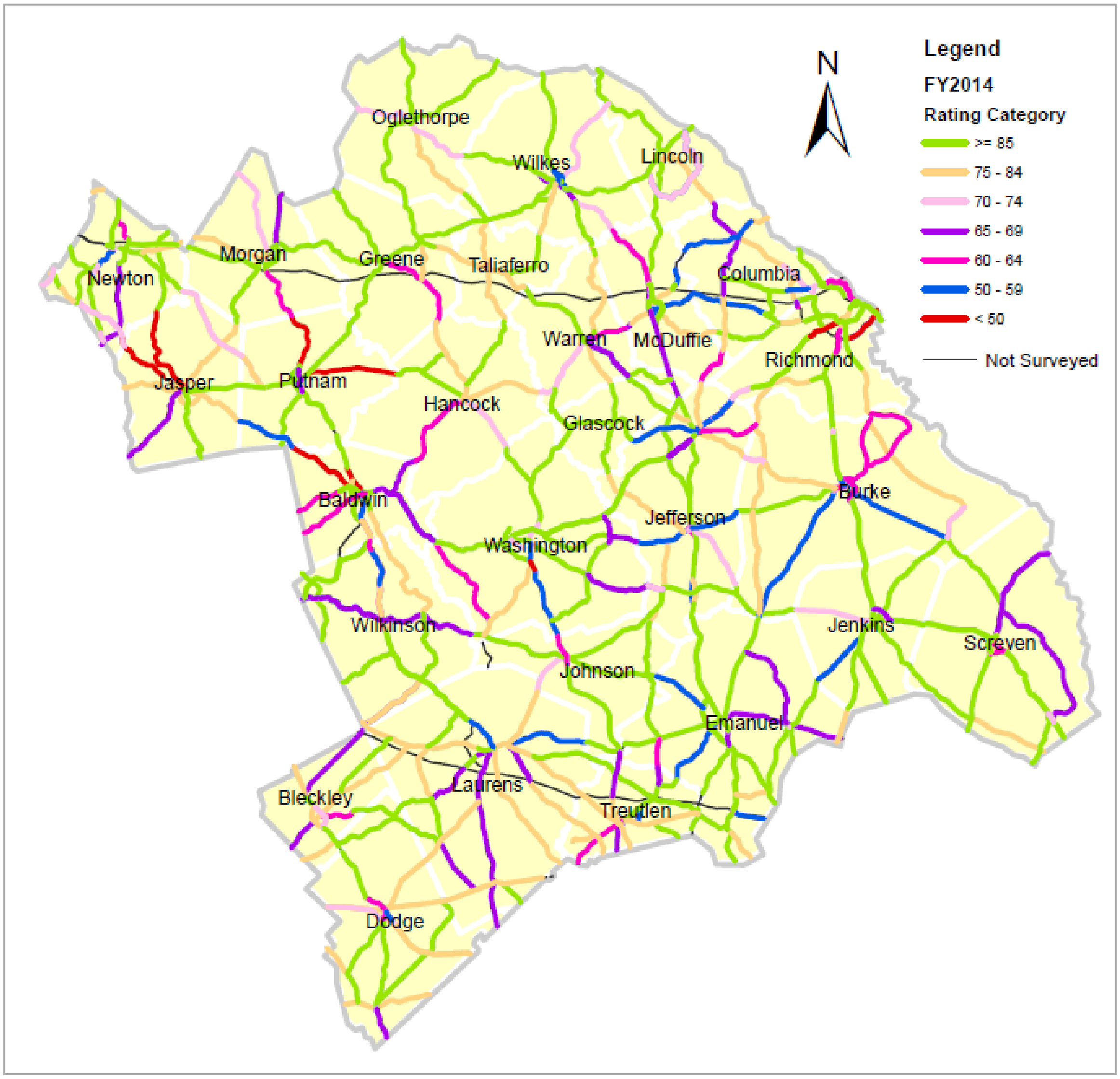


Figure 5.10 District 2 pavement condition in FY 2014

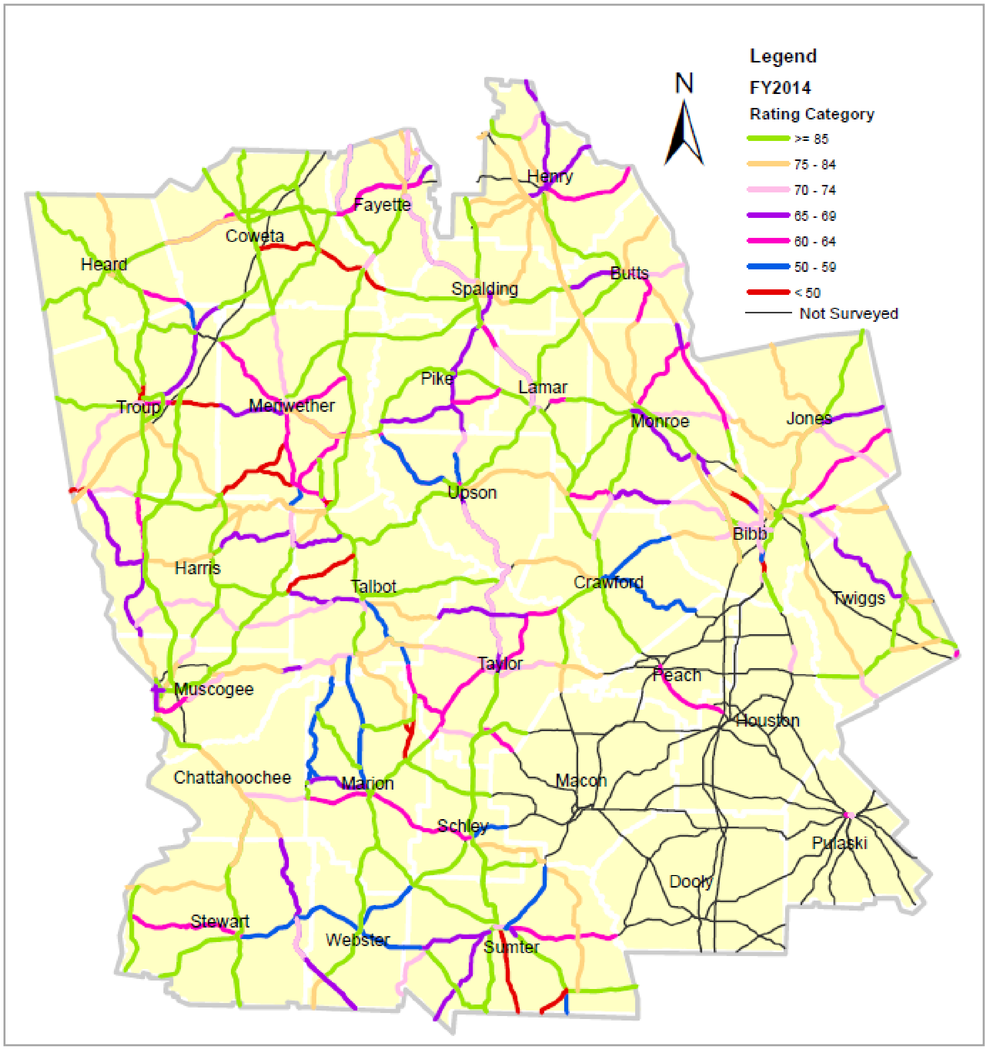


Figure 5.11 District 3 pavement condition in FY 2014

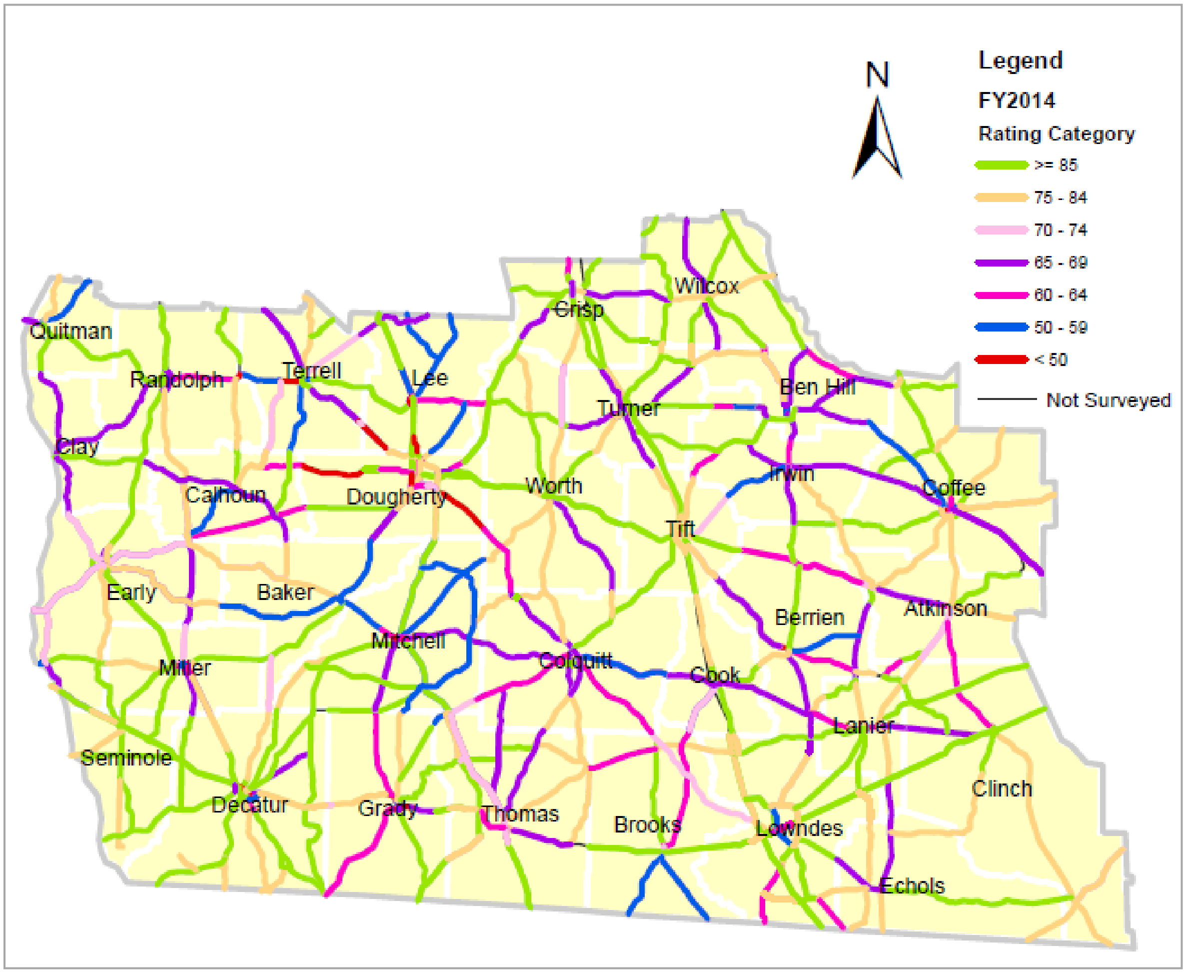


Figure 5.12 District 4 pavement condition in FY 2014

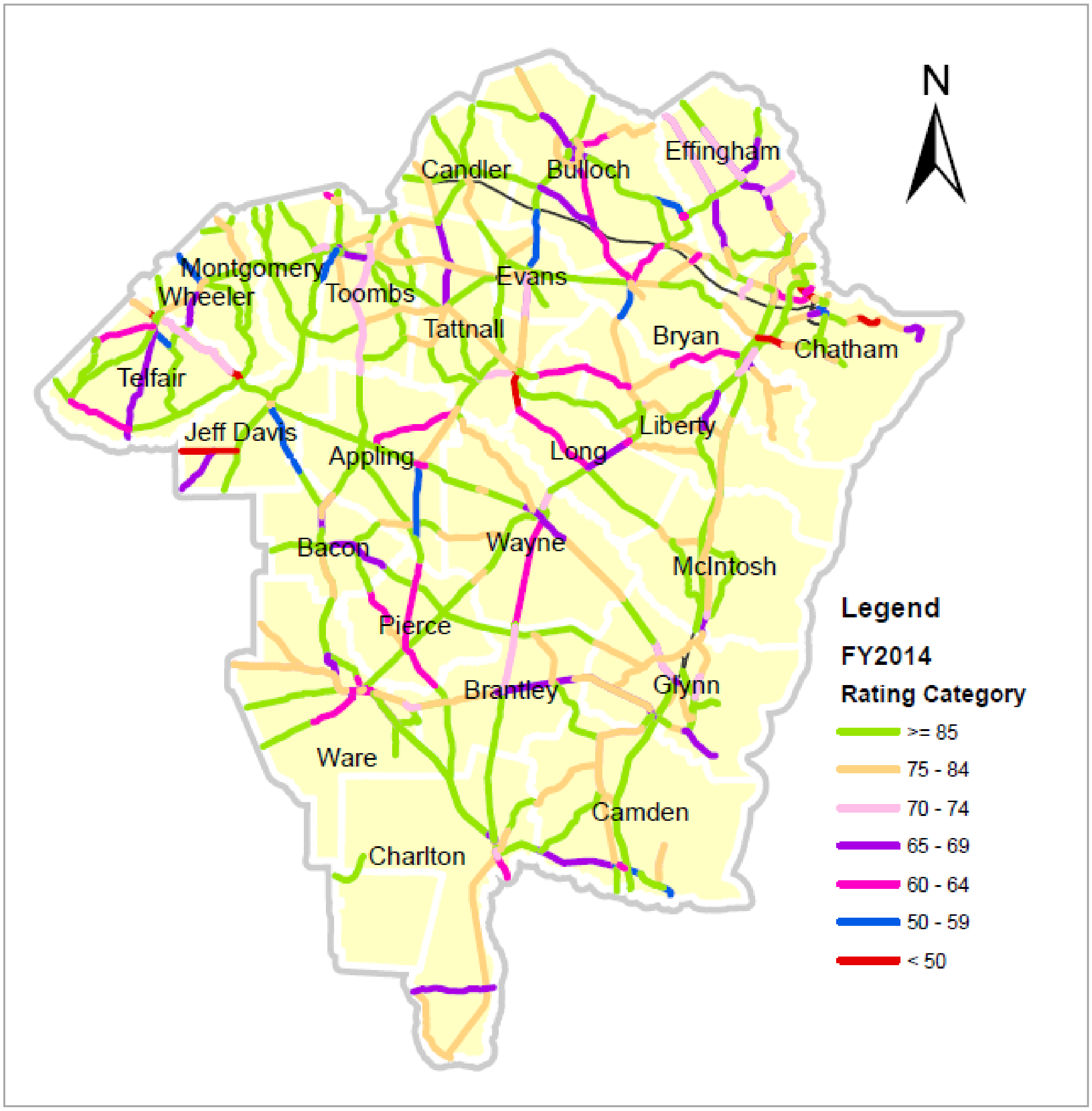


Figure 5.13 District 5 pavement condition in FY 2014

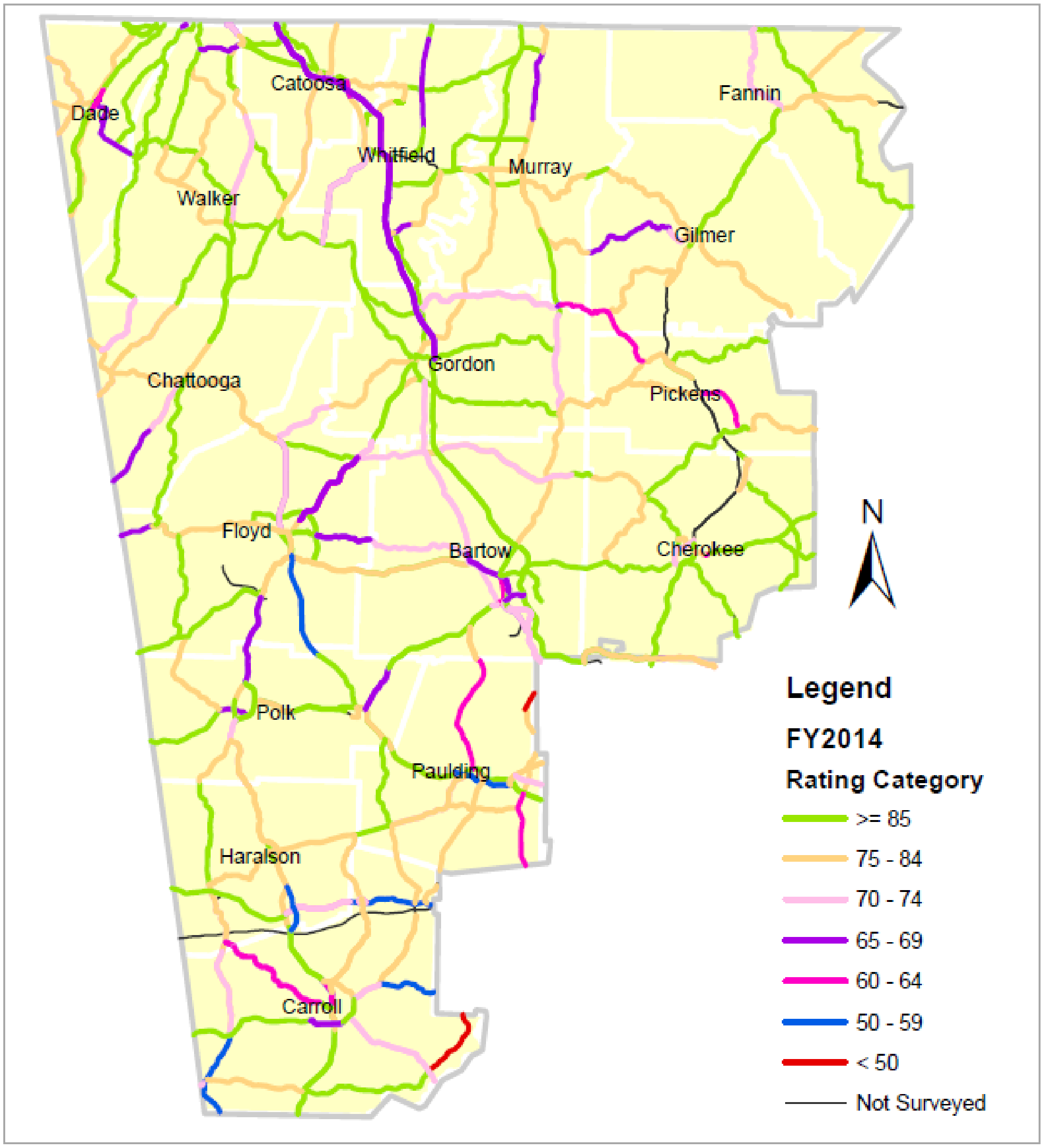


Figure 5.14 District 6 pavement condition in FY 2014

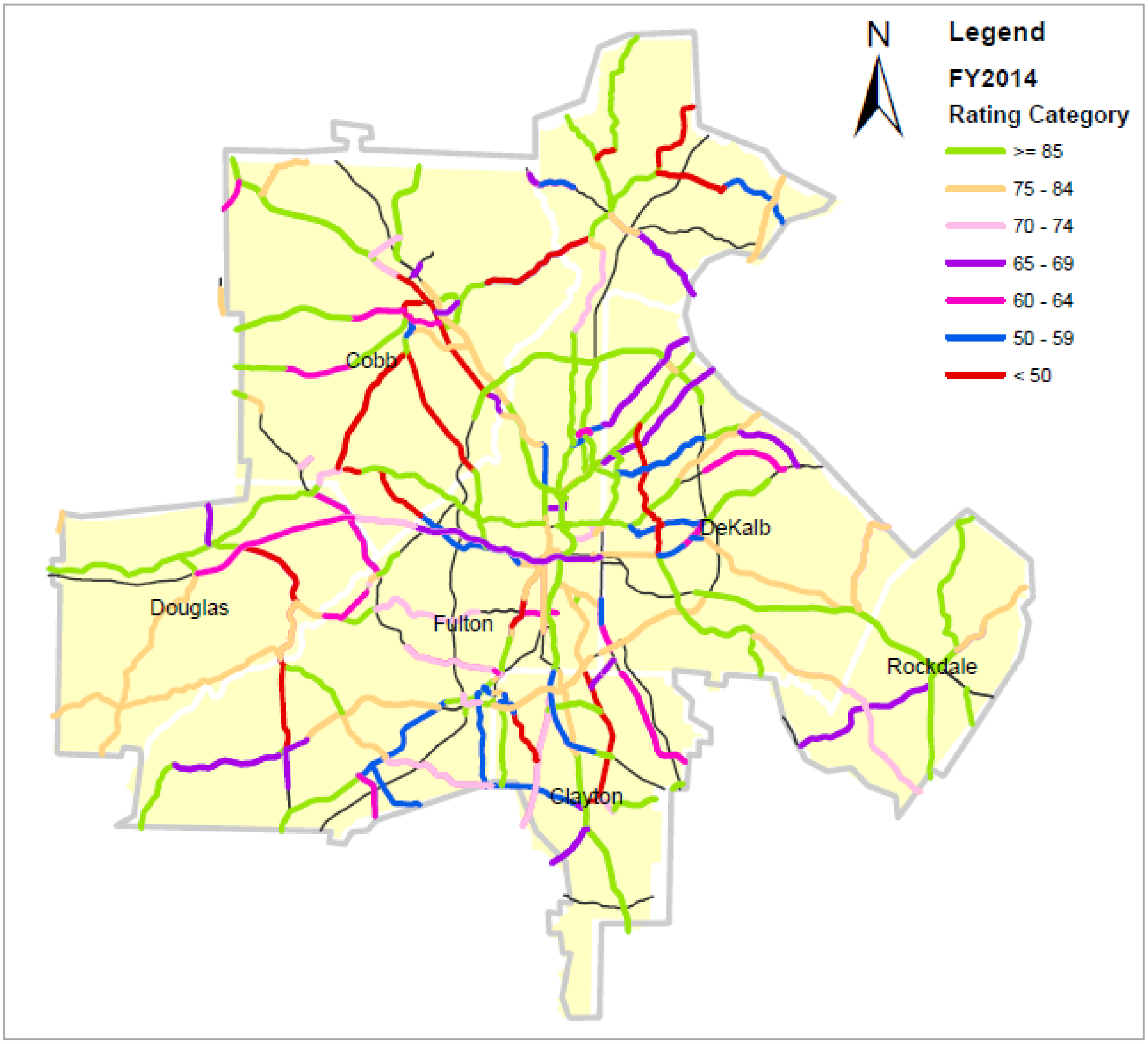


Figure 5.15 District 7 pavement condition in FY 2014

5.4 Summary

Historically, approximately 51% of the 370 pavement resurfacing cycles have been delayed for more than one year. Among them, 7% were treated at a rating less than 55. Analysis of RBR shows it has decreased in recent years, which indicates the pavements have not been resurfaced in recent years. This corresponds to the decline of the pavement condition at the network level. A consistent and rapid decline in the composite rating is observed since FY 2002. The composite rating dropped from 88.4 in FY2002 to 79.8 in FY 2014 and has not been able to meet the network performance goal of 85 since 2007. The pavements with a resurfacing delay (i.e., a rating less than 70) increased significantly from 18% in 2010 to 25% in 2014; 4% of the pavements were in bad condition (e.g., a rating less than 55). More expensive treatment could be required for fixing these low-rated projects. In 2014, approximately 25% (4,691 surveyed-miles) of the pavements had ratings less than 70, which were due or past due for resurfacing. These include 139 surveyed miles on interstate highways and 4,552 surveyed miles on non-interstate highways. Districts 3 and 7 have the largest resurfacing delay of 64 and 50 surveyed miles on interstates; District 4 has the largest resurfacing delay of 1,174 surveyed miles on non-interstate highways. Adequate funding and proper programming are needed for achieving the performance goal (i.e., a composite rating of 85) at the network level.

6 CONSEQUENCES OF DELAYED PAVEMENT RESURFACING

Treating pavements with the right method at the right time and right location is crucial for establishing a cost-effective and sustainable pavement management (NCHRP, 2004; NCHRP, 2011; Xu & Tsai, 2012). According to GDOT's Chief Engineer, Ms. Meg Prikle, GDOT has established its pavement preservation program based on the 3R concept (right time, right treatment, and right location) to ensure it spends money wisely to cost-effectively sustain its pavements (GDOT, 2014). GDOT has an active and effective pavement preservation program, which focuses on applying thin resurfacing (e.g., 1.5-in) at the right time to prolong pavement service interval/life without getting into expensive treatment, such as major rehabilitation. However, with funding shortages in the past 10 years, pavement preservation, especially pavement resurfacing, has been delayed substantially. Applying the pavement resurfacing at the right time is very crucial for achieving high performance and pavement longevity, and minimizing the total life-cycle cost of a project. On the contrary, studies (NCHRP 2004; NCHRP 2011) show that delaying pavement preservation would cause 1) decreased pavement resurfacing effectiveness (e.g., shortened resurfacing service interval/life, 2) increased construction costs because of additional pre-treatment or more expensive treatment category (Xu & Tsai, 2012; NCHRP, 2005), and 3) increased user costs due to roughness/discomfort pavements. In addition, the delayed resurfacing can cause roadway safety concerns due to pavement defects, such as rutting, raveling, and friction (splashing and flashing in OGFC). However, there is a lack of quantitative evidences (e.g., shortened service interval, increased construction costs and user costs) to support them. This chapter presents the analyses of the changes in the Pavement 70 Interval, the construction costs, and the user costs caused by the delayed resurfacing to provide quantitative evidence on the consequences of delayed resurfacing. First, a literature review was conducted on the potential the impact of the pavement resurfacing delay. Second, the impact of pavement resurfacing delay, i.e., RBR, on the subsequent pavement service interval was analyzed using the 370 high-quality pavement resurfacing cycles. Finally, a case study using 3D sensing, video log, and GPS data, collected for the past six years, and 14 years of COAPCES data was conducted on S.R. 26 near the Port of Savannah to quantitatively evaluate the increased construction cost and user cost associated with the pavement resurfacing delay.

6.1 Review of Impacts of Pavement Resurfacing Delay

This section summarizes the review on the previous studies on the consequences of delayed pavement maintenance, preservation, and rehabilitation with a focus on the pavement resurfacing delay. There are limited studies (NCHRP, 2011; Xu & Tsai, 2012) on the consequences of delayed pavement maintenance, preservation, and rehabilitation; most of the studies (NCHRP, 2004; Labi, 2012) focus on the effectiveness or life-cycle cost analysis (LCCA) on certain treatment methods. The consequences of delayed maintenance, preservation, and rehabilitation on transportation assets include 1) reduced pavement resurfacing effectiveness, 2) increased construction costs, 3) increased user costs, 4) increased risk of failure during catastrophic events, 5) increased risk of failure under normal condition, 6) decreased safety, and 7) loss of public support for transportation agencies (NCHRP, 2011). Among them, the reduced pavement resurfacing effectiveness, increased construction costs, and increased user costs are often studied quantitatively using a life-cycle cost analysis (LCCA) approach.

Several past studies focus on addressing the issue of delaying maintenance and its financial effects. The World Bank (Paterson et al., 1989) conducted a study and concluded that, in general, deferring the maintenance of pavements that are in relatively good condition to the point that they are in poor condition would result in an increase in maintenance cost by approximately 400-500%. Some other studies (Sharaf et al., 1987, 1988) reported that every unit of maintenance cost spent at the proper time will save 4–7 units of maintenance cost over the cost of maintenance deferred to the failure condition. Sharaf (1998) quantified the economic effect of deferring preventive maintenance on maintenance costs. The results showed that, on average, the annual maintenance costs of pavements in poor condition would be as much as four times the costs of pavements maintained while they are in good condition. Chasey et al. (2002) used dynamic simulation techniques and a hypothetical regional pavement system to illustrate the effect of deferred maintenance on expenditure and investment cost-effectiveness at a system wide level. However, these studies focus on the network-level application; all the pavement condition and maintenance needs are often based on engineering judgment and/or prediction models instead of actual data. This would lead to uncertain analysis results.

In previous studies, the effectiveness of a pavement maintenance, preservation, and rehabilitation is usually measured by one of three methods: 1) the performance jump/improvement immediately after the treatment applied, 2) the time or accumulated traffic volume to reach a predefined performance threshold (or extension in pavement service life), or 3) the area under the performance curve (Labi, et al., 2005, Tsai & Xu, 2011; NCHRP, 2004). Figure 6.1 illustrates these three methods. As shown in Figure 6.1, the performance jump/improvement (indicated as A) represents a short-term effectiveness, and intensive data is required for computing the area under the performance curve (indicated as C). Method 2 (life of the treatment to reach a predefined performance threshold) is commonly used in the studies for measuring the effectiveness. Different performance indicators, such as pavement structural condition (PSC) and used by the Washington Department of Transportation (WSDOT 1999b), pavement serviceability rating (PSR) used by the Indiana Department of Transportation (WSDOT 1999a), and the rut depth and IRI (Peshkin et al., 2004; Tsai & Wu 2006) have been used. The selection of the performance indicator is based on agency's practices, i.e., tied with the treatment criteria, and data availability.

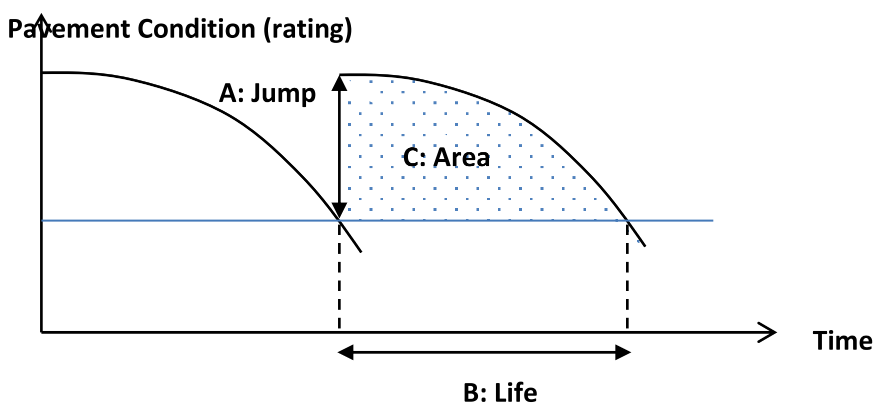


Figure 6.1 Illustration of Methods for Measuring Effectiveness

In summary, the studies, especially the quantitative studies, on the reduced delayed pavement maintenance, preservation, and rehabilitation focus on the reduced pavement resurfacing effectiveness, increased construction costs, and increased user costs are limited. LCCA is often used to assess scenarios with different treatment method, timing, maintenance activities, etc. However, the inputs (e.g., service interval/life) are often based on engineers' experience and/or prediction models. There are limited studies on the quantitative evidence based on actual data (e.g., pavement condition data). Therefore, there is a need to quantify the impacts of a pavement resurfacing delay.

Due to the data availability, this chapter focuses on analyzing the impact of the pavement resurfacing delay on 1) the reduced resurfacing effectiveness, 2) increased construction costs (e.g., additional deep patching costs), and 3) increased user costs (e.g., vehicle operating costs) because of poor pavement condition.

6.2 Study of Reduced Pavement Resurfacing Effectiveness on Selected Projects

Pavement resurfacing (1.5-in resurfacing to replace the surface layer) is one of the pavement preservation methods most commonly used in Georgia. GDOT has established a practice to applying pavement resurfacing at a rating of 70, which is considered to be the right timing to keep the base in a good condition. Thus, the Pavement 70 Interval is used as the measures for the resurfacing effectiveness. It was assumed that the resurfacing effectiveness would be reduced significantly (e.g. reduced Pavement 70 Interval) if the pavement resurfacing was delayed significantly to a rating less than 70 (e.g. low RBR). Consequently, the effective number of resurfacing cycles would be reduced. However, these assumptions have not been validated with actual performance data. Thus, the research questions for this study were:

1. Would the resurfacing effectiveness be decreased with the RBR less than 70? If yes, what is the reduction of resurfacing effectiveness?
2. Would the number of resurfacing cycles be reduced because of the resurfacing delay?

The Pavement 70 Interval and the corresponding RBR for the 370 high-quality resurfacing cycles are plotted and shown in Figure 6.2. There is a slightly increasing trend in the Pavement 70 Interval as the RBR increases. The pavements resurfaced below a rating of 60 have a lower Pavement 70 Interval compared to those resurfaced above a rating of 60. However, the data is scattered with a large variation (a wide range of the Pavement 70 Intervals given an RBR), especially for the projects resurfaced with a rating greater than 60. This could be because the 370 resurfacing cycles have different pavement designs, construction quality, traffic conditions, environments (e.g., temperature, snow, flood, etc.), application of maintenance and maintenance levels (e.g., crack seal and strip seal), and resurfacing methods (e.g., milling, deep patching, resurfacing thickness, etc.). All these factors can influence the effectiveness of pavement resurfacing, in additional to RBR. For example, a major rehabilitation and a typical 1.5-in resurfacing would have different effectiveness in terms of the Pavement 70 Interval. The use of pavement preventive methods, such as crack sealing, strip seal, etc., on good/fair pavements could potentially increase the pavement service interval. Therefore, it is essential to evaluate the pavement resurfacing effectiveness using a subset of projects with more uniform conditions (e.g., pavement design, traffic, resurfacing method, etc.)

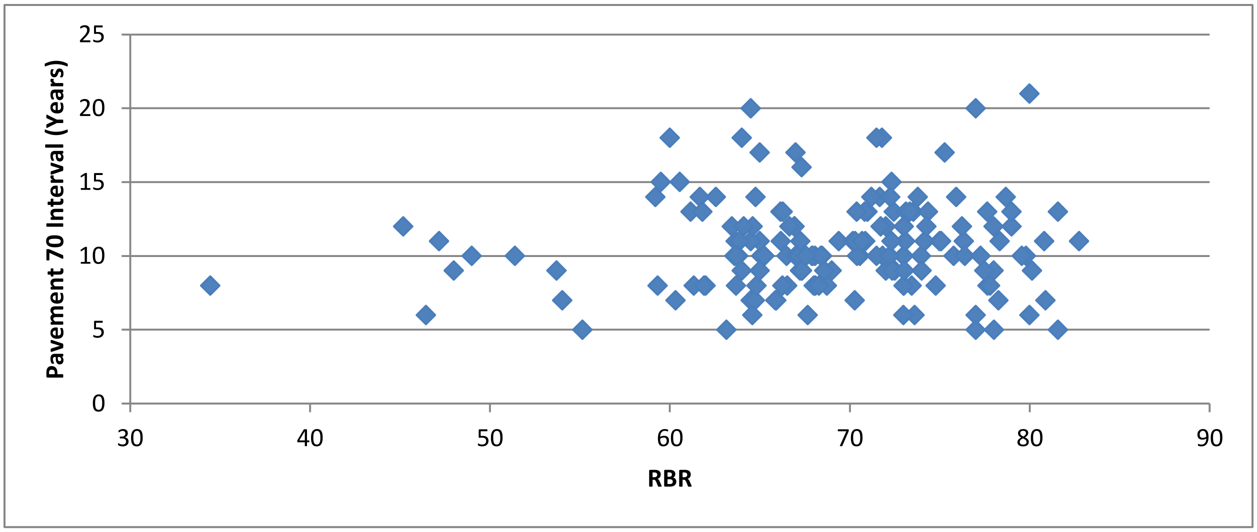


Figure 6.2 Pavement 70 Interval vs. RBR

Table 6.1 lists the average Pavement 70 Interval by RBR category (greater or lower than 60) under different traffic categories. It shows that the projects with a high AADT have the largest differences in the Pavement 70 Interval for the projects resurfaced below and above a rating of 60. This might imply the pavements having resurfacing delays might have higher impact on the shortened Pavement 70 Interval for the pavements with high traffic volume than those with lower traffic volume. Thus, a subset of the data with high traffic volume was selected for the subsequent analysis.

Table 6.1 RBR and Average Pavement 70 Interval by AADT Category

AADT	RBR	Average Pavement 70 Interval
High (> 10000)	>=60	10.9
	< 60	10.2
Medium (5001 – 10000)	>=60	10.3
	< 60	10.0
Low (< 5000)	>=60	11.1
	< 60	10.7

Based on previous analysis, a subset of data with high traffic volume is chosen to support the subsequent analysis. A total of 13 resurfacing cycles with an AADT greater than 10,000 were selected for further analysis. Figure 6.3 shows the Pavement 70 Interval and RBR for this set of data. It shows a clear, increasing trend between the Pavement 70 Interval and the RBR, except for two points. These two projects were carefully reviewed and additional information, including pavement design and maintenance history, was acquired from GDOT to explain their performance. The project labeled “Major Rehab” had major rehabilitation instead of typical 1.5-in resurfacing; thus, it has a longer pavement life. This project was removed because it is not a resurfacing project. A review of another project labeled “Crack Seal” shows preventive maintenance, such as crack seal, was performed on it at a rating of 86. The rating did not drop for 2-3 years after the application; the pavement life was extended by the crack seal. This project was also removed.

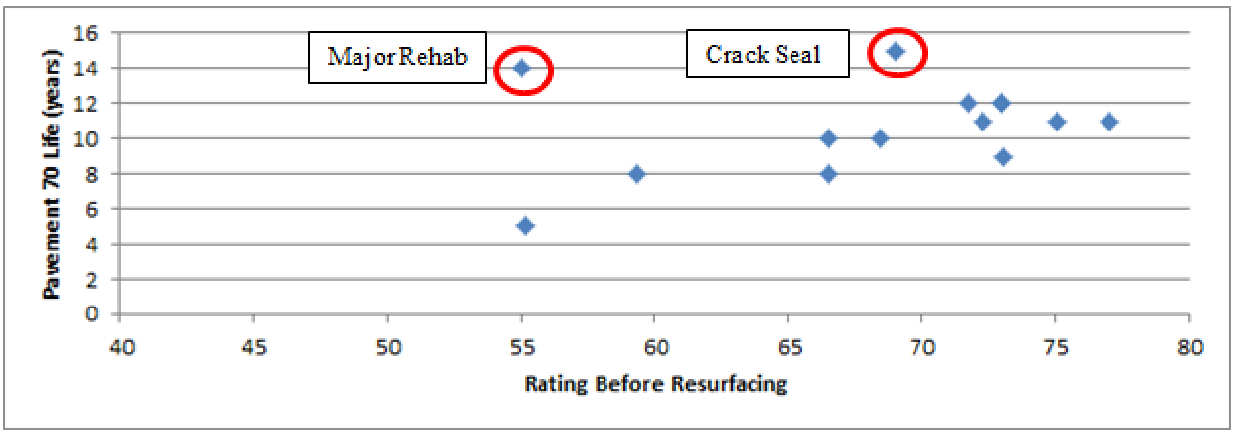


Figure 6.3 Pavement 70 Interval vs. RBR for 13 projects

After excluding these two projects, a clear, positive trend can be found between the Pavement 70 Interval and the RBR, as shown in Figure 6.4. Based on this trend, the Pavement Resurfacing Interval was estimated at 10 years and 9 years when resurfaced at a rating of 70 and 65, respectively. This indicates a pavement resurfacing delay (at a rating of 65) could result in a 1-year reduction in the pavement life (1/10; 10% of reduction in resurface effectiveness) compared to the resurfacing performed at the right timing (a rating of 70). An RBR at 55 results in more than 40% ((10-6)/10) reduction in resurfacing effectiveness. This finding confirms the original assumption that the resurfacing effectiveness will decrease with an RBR of less than 70, and it would reduce more than 10% for every 5 rating intervals. This finding suggests that it is more cost-effective to apply resurfacing at the right timing than to delay the pavement resurfacing to a later time (e.g., a rating of 55). Because of the intensive data collection and filtering on each project and discussing with GDOT engineers the treatment method (e.g. major rehab and resurfacing) and the preservation activities, only a limited number of projects (12) were processed and analyzed to demonstrate the impact of pavement resurfacing delay. Thus, further study is recommended to analyze more resurfacing cycles with different characteristics, traffic volumes, and functional class and to better understand the impact of pavement resurfacing delay on it effectiveness in terms of Pavement 70 Interval. It is recommended that GDOT establishes a database to record the treatment method and year of treatment along with preservation activities (e.g. strip seal, crack seal, etc.) applied to facilitate data analysis. Further study of the impact of resurfacing delay on the reduced number of resurfacing cycles when the data with multiple resurfacing cycles is available is also recommended.

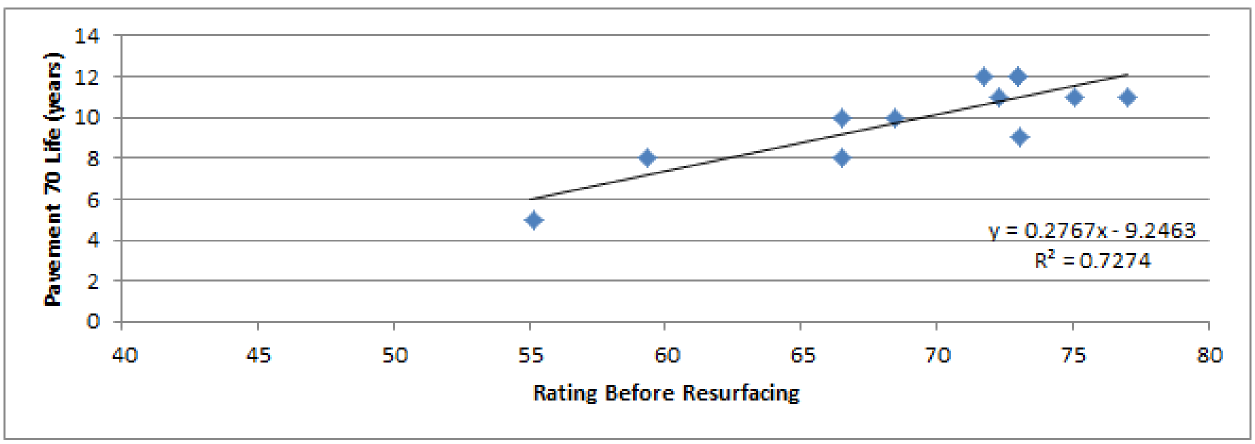


Figure 6.4 Pavement 70 Interval vs. RBR for 11 projects (after outliers are removed)

6.3 Study of Increased Construction Costs and User Costs on S.R. 26/U.S. 80

Figure 6.5 illustrates the potential impacts of delaying pavement resurfacing on the treatment method. As pavement deteriorates, it reaches target value (i.e., a rating of 70) for triggering resurfacing. If the pavement is left without resurfacing, there is a window of time (or a range of pavement conditions), referred to as Stage 1, in which the same pavement resurfacing can still be applied with additional pre-treatment, such as deep patching. It is assumed that the majority of the distresses are within the surface layer (that is, they do not go beyond the surface layer) except for some localized areas where deep patching may be required. The need for deep patching is expected to increase as the pavement deteriorates within Stage 1. If the pavement continues deteriorating without resurfacing, it will reach Stage 2, in which the distresses are beyond the surface layer. A much more expensive treatment, such as major rehabilitation, is then needed. According to GDOT engineers, the majority of the delayed resurfacing pavements in Georgia are in Stage 1, since the resurfacing programming process is designed to prevent the pavements from falling into Stage 2. In addition, as the pavement continues deteriorating, the pavement becomes rougher because of more severe rutting, potholes, etc. Compared to smooth pavements, rough pavements increase user costs in terms of vehicle repair, tire wear, and fuel consumption. Therefore, this section performs a case study that focuses on a one-mile segment on S.R. 26/U.S. 80 near the Port of Savannah to quantify the increased construction costs and user costs as the result of pavement resurfacing being delayed. The study uses long-term pavement performance data, including video log images, 3D pavement data, and GPS data, collected from 2011 to 2016 using Ga Tech's sensing vehicle. The site information, historical COPACES data on the site, and analysis of construction costs and user costs are discussed in the subsequent sub-sections.

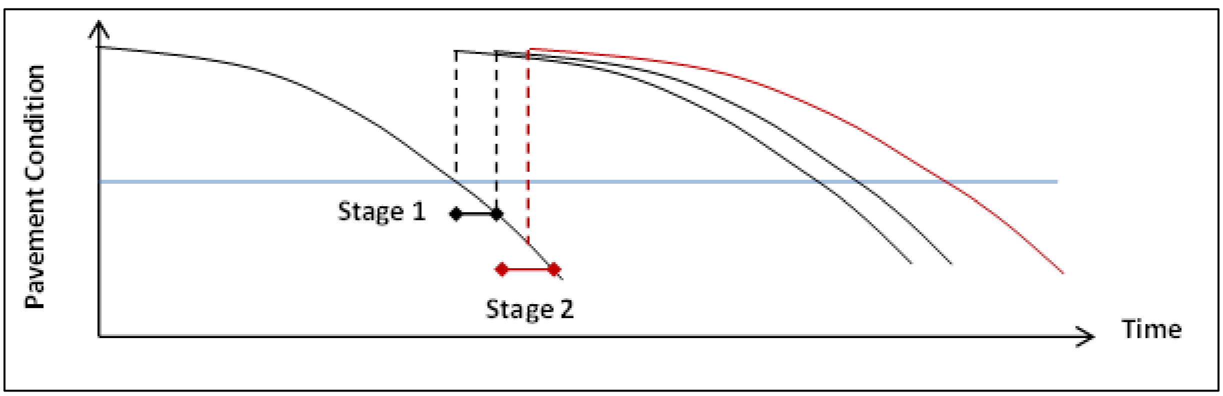


Figure 6.5 Illustration of potential treatments at different times (pavement conditions)

6.3.1 Site Description on S.R. 26

The case study was conducted on a one-mile section on S.R. 26/U.S. 80 in Chatham County near the Port of Savannah. S.R. 26 and U.S. 80 are concurrent on this section of roadway; S.R. 26 is used in this report. This section of roadways is part of Georgia's freight route system and connects to the Port of Savannah. The exact location of the section is located at Mileposts 10 to 11 on S.R. 26, west of I-516, as shown in Figure 6.6.

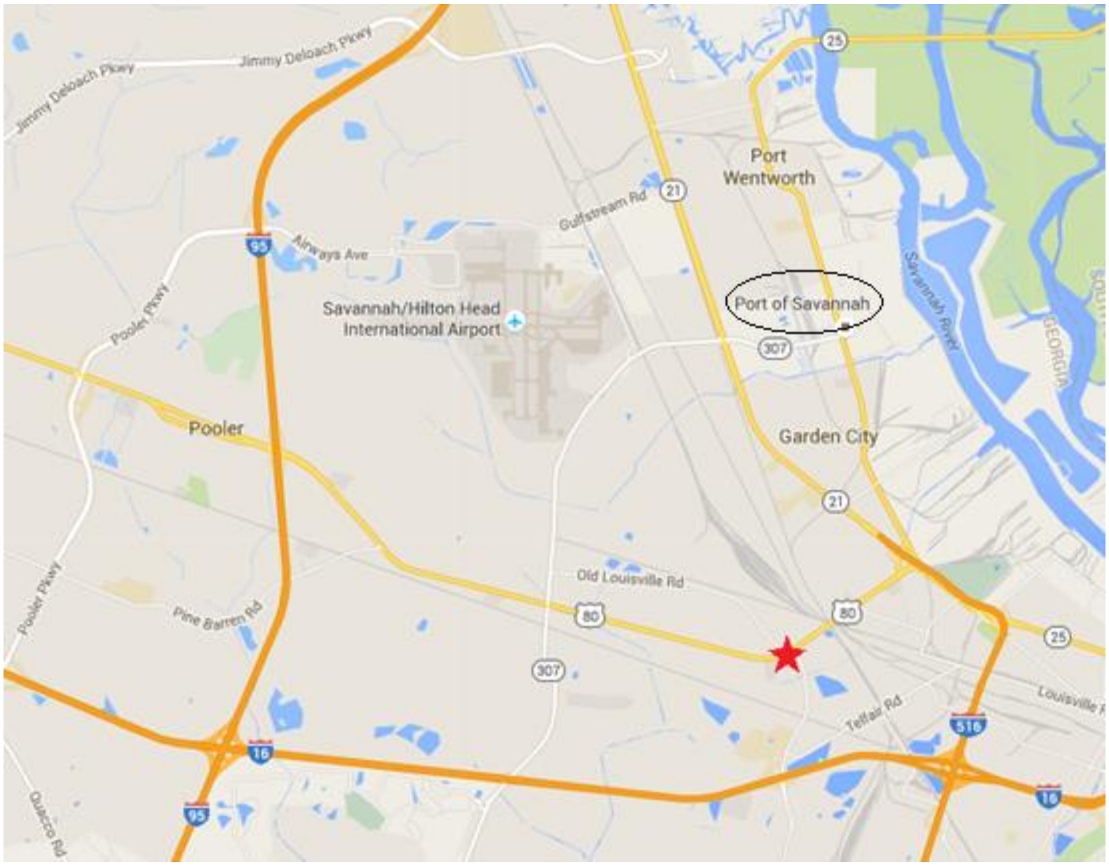


Figure 6.6 Site location (S.R. 26 in Chatham County near the Port of Savannah)

This section is a 4-lane roadway with 2 lanes in each direction. The average annual daily traffic (AADT) in 2014 was 21,000 vehicles per day, 12% of which is truck traffic (2,500 trucks per day). Historical traffic data from 1990 to 2014 is shown in Figure 6.7. This section was widened in 1996 with 7.5-in of asphalt mixtures on top of 8-in of graded aggregate base (GAB). The top three layers were 1.5-in of dense-graded layer (12.5 mm SuperPave), 2-in of an asphaltic concrete "B" (19 mm), and 4-in of an asphaltic concrete base (25 mm), as shown in Figure 6.8. It was last milled and resurfaced in 2005 with 1.5-in of 12.5 mm SuperPave. According to the COPACES survey conducted by GDOT, this section was given a rating of 65 in FY 2012. However, it has not been resurfaced at the time this report was prepared (early 2016). It has been let for resurfacing and is expected to be resurfaced in 2016.

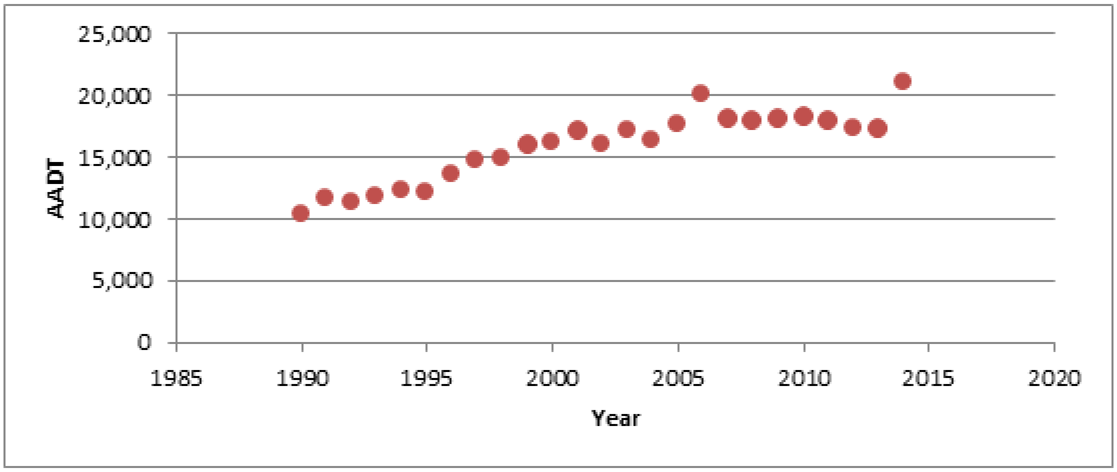


Figure 6.7 AADT on S.R. 26 (source: http://geocounts.com/gdot/)

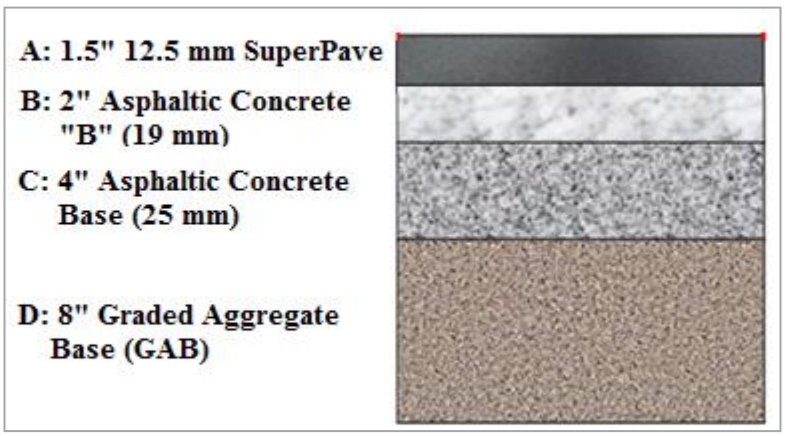


Figure 6.8 Pavement design for the site.

6.3.2 *Pavement Condition on S.R. 26*

An annual pavement condition survey has been conducted on this segment since 1986 based on GDOT COPACES distress protocol. A COPACES survey involves a person surveying the pavements and recording the severity and extent of ten types of pavement surface distresses for each mile-long segment. Historical COPACES data, including rating and predominant distresses for MP 10-11 in the current pavement cycle from FY 2005 to FY 2015, is shown in Figure 6.9. A rating of 100 was reported in FY 2005 and FY 2006 after resurfacing. The deterioration of rating and distresses exhibited two types of behaviors – before and after FY 2012. Before FY 2012, only Severity Level 1 load cracking was recorded; after FY 2012, more severe cracking (Severity Levels 2 and load cracking and block cracking) was reported with a rapid decrease in the rating. Severity Level 1 load cracking was first reported in FY 2007, two years after the resurfacing, and reached an extent of 100% in FY 2010. It is noted that the extent of load cracking Severity Level 1 was 100% in FY 2010, FY 2011, and FY 2012, and the ratings were similar in these three years. The rating dropped to 65 in FY 2012 after being in service for eight years. At the time, in addition to Severity Level 1 load cracking, Severity Level 2 load cracking and block cracking were reported. According to GDOT's resurfacing criteria, resurfacing was needed in 2012 when the rating was 65. Due to funding shortages, this project was not resurfaced. It is scheduled to be resurfaced in FY 2016. This means the resurfacing has been delayed since FY 2012. Figure 6.9 shows the pavement has deteriorated with more severe distresses since FY 2012. The rating has dropped significantly since FY 2012 at a rate of 8.5 points per year. The rating was 36 and 31 in FY 2014 and FY 2015, respectively. More importantly, Severity Level 3 load cracking and Severity Level 3 block cracking were reported in these two years. This section allows us to observe the pavement delay conditions in detail and study their impact on additional construction costs and user costs. It is noted that as the pavements deteriorated, potholes and pop-outs were observed at some isolated locations. GDOT's maintenance crew applied patches and spot overlay at some locations between FY 2012 and FY 2014 to maintain the service level and safety of the road and to prevent further deterioration of the underlying subsurface.

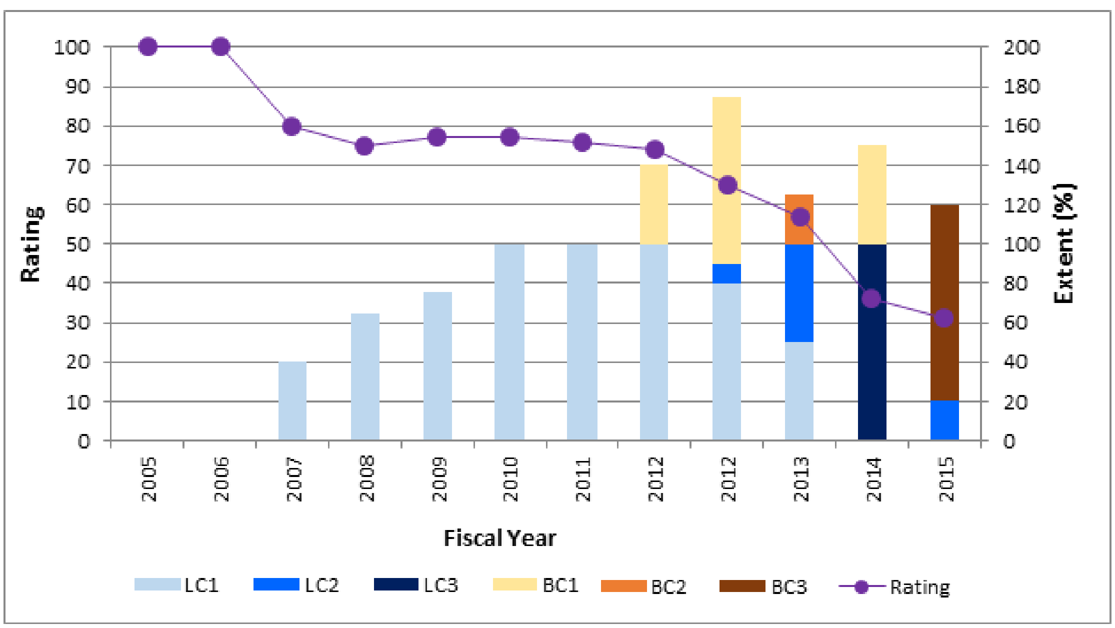


Figure 6.9 COPACES Data S.R. 26 from FY 2005 to FY 2015

6.3.3 Increased Construction Costs

As pavement resurfacing is delayed, pavements will degrade with more distresses. According to GDOT's practices, a typical 1.5-in resurfacing can be applied on a project with isolated, severe distresses by the use of pretreatment, like deep patching. Figure 6.10 shows the examples of pavements with different conditions requiring different treatments. Figure 6.10(a) shows that a pavement is in fair condition with Severity Level 2 load cracking based on COPACES surface condition evaluation, and the corresponding coring information matches with surface distress condition assessment. Thus, the typical 1.5-in resurfacing is sufficient for treating this pavement condition. Figure 6.10 (b) shows that pavement with Severity Level 3 load cracking, based on COPACES surface condition evaluation and the corresponding coring information, has cracks that are crumbling, and deep patching is needed in addition to resurfacing. Deep patching is applied on localized areas identified by project engineers and conducted prior application of 1.5-in milling and resurfacing to remove the damaged areas that have cracks deeper than 1.5-in to provide an even and sound surface for resurfacing; milling and resurfacing are also applied on the deep patched surface. Determination of the need for deep patching heavily depends only on the surface distress assessment because it is too expensive to take cores for the entire project.

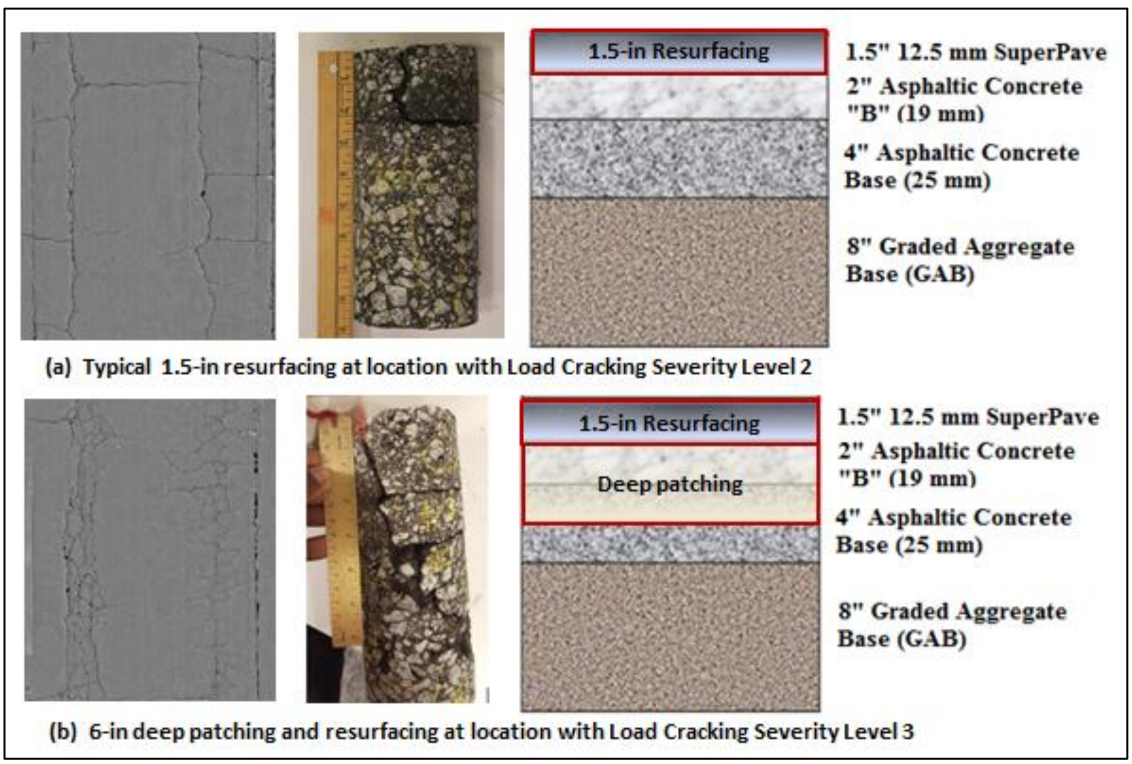


Figure 6.10 Illustration of deep patching, milling and resurfacing

COPACES data provides an assessment of the overall pavement condition on a segment to support decisions on selecting an adequate treatment method. However, the cracking information provided by COPACES was based on a 100-ft sample location instead of the entire 1-mile segment and could not provide sufficient information for identifying the localized distressed areas requiring deep patching. Thus, the deep patching area was determined based on the criteria advised by Mr. Ritchie Swindell, the State Maintenance Liaison, using detailed, full-coverage surface distress data derived from long-term performance monitoring data to provide a consistent and quantitative cost estimate for deep patching. This process was repeated for the data collected between 2011 and 2016 to estimate deep patching costs under different pavement conditions. It is briefly described as follows:

- First, the 3D pavement data was processed at every 5-m interval along the one-mile section using a semi-automatic method to extract the surface distress data, including cracks, rutting, and other distresses. Surface distresses, mainly cracking and rutting, were automatically extracted and classified using the algorithms developed by the Ga Tech research team.
- The area requiring deep patching was determined based on the surface distress data and criteria provided by Mr. Ritchie Swindell. Deep patching is required at locations with load cracking Severity Levels 3 and 4, potholes, severe rutting, and/or longitudinal cracks that are close and form small polygons with pop-outs. Figure 6.11 shows examples of the areas that require deep patching. The research team worked with Mr. Ritchie Swindell to review the surface distress data and image for each 5-m interval to determine deep patching areas. The area was determined to be in the left and/or right wheel path, and each wheel path was assumed to be 3-ft wide; the length can be either 5-m (full length) or 2.5-m (partial length) in each 5-m image. The review process was repeated on each 5-m image for the data collected from 2011 to 2016.

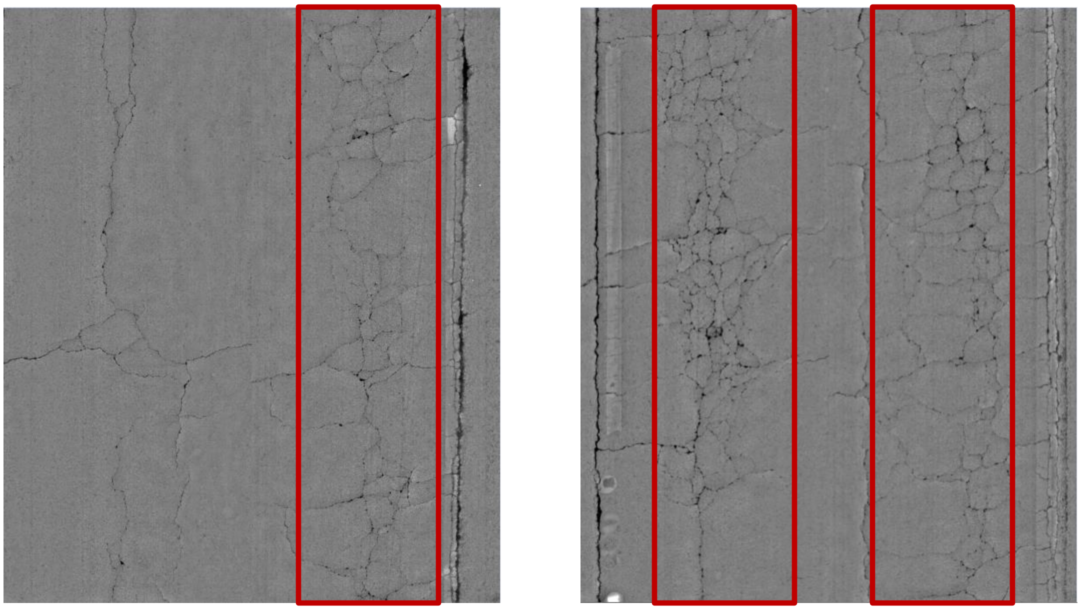


Figure 6.11 Examples of the spots requiring deep patching

- A total of 5 cores were taken on the 1-mile test section to verify the depth needed for the deep patching. Two of the five cores were broken; 3 cores had cracks beyond the surface layer and were deeper than 4-in. Figure 6.12 shows two cores taken from S.R. 26. After discussion with GDOT's expert, it was determined that a 4-in deep patch was required at the locations with severe load cracking. It is noted that a 4-in deep patching was assumed for all years (2011 to 2016).

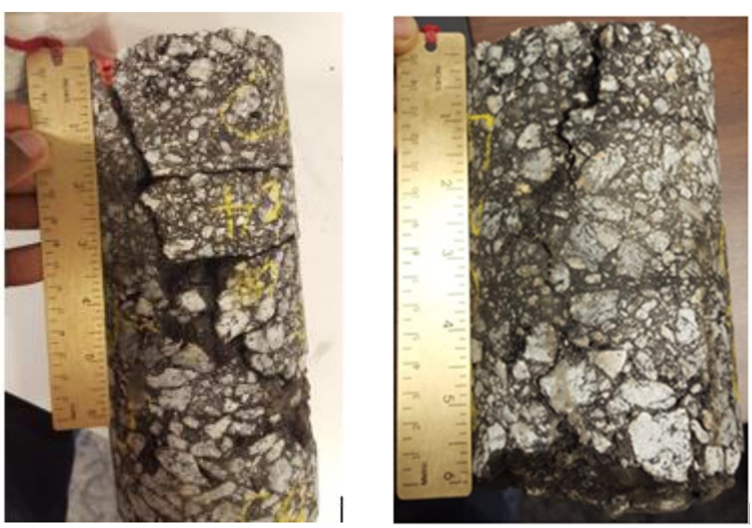


Figure 6.12 Examples of cores taken in S.R. 26

- The cost was computed based on GDOT's Item Mean Summary for 2012, as shown in Table 6.2. The unit price included the labor, equipment, and material costs for the resurfacing and deep patching; traffic control was not included. It is noted that deep patching operations are performed separately before milling and resurfacing and require additional traffic control.

Table 6.2 Unit price for milling, resurfacing and deep patching

	Unit	**Unit Price**
Milling	Yard^2	2.54
Resurfacing (1.5-in 12.5 mm SuperPave) 165 lb per sq yard	Ton	83.6
Deep patching 110 lb per sq yard (per inch)	Ton	84.1

Table 6.3 summarizes the area requiring deep patching for each year based on the data collected between 2011 and 2016. The areas requiring deep patching increased as the pavements deteriorated with time. The area for deep patching was estimated at 339 sq yard, 9.6% of the wheel path area (5280ft * 6ft = 3520 sq yard), in December, 2011; extensive deep patching (37.7%) is required in the wheel path area by 2016. It is noted that patches by GDOT's maintenance crew were observed in the wheel paths. Figure 6.13 shows an example of the pavement deterioration using 3D pavement data. Figure 6.13 shows the load cracking in one area connected and formed small polygons over time; denser and smaller polygons were formed and can be observed in 2012. Eventually, a small pothole was observed in 2014, and it was patched in 2015, as shown in Figure 6.13. Based on these results and the unit price, the construction costs were computed for each timestamp.

Table 6.3 Area Requiring Deep Patching on S.R. 26

Deep Patching	12/6/2011	7/13/2012	3/20/2013	12/7/2013	7/18/2014	6/15/2015	2/20/2016
Area (sq yard)	339	454	681	719	962	1,006	1,326
% of wheel path area (3520 sq yard)	9.6%	12.9%	19.3%	20.4%	27.3%	28.6%	37.7%

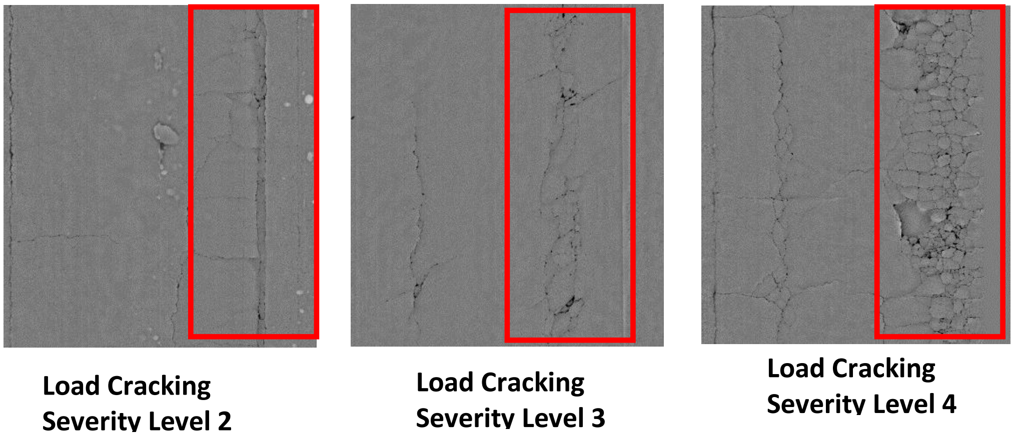


Figure 6.13 Examples of 3D Pavement Data on S.R. 26

Table 6.4 summarizes the construction costs, including milling, resurfacing, and deep patching in each timestamp between 2011 and 2016; the COPACES rating was also included in the table. The estimated costs for milling and resurfacing remain the same ($65,683), while the costs for deep patching increased as the pavements deteriorated. Figure 6.14 shows there was a steady increase in the cost for deep patching, approximately $4,300 per lane-mile per year (6.5% of the milling and resurfacing costs), as the rating decreased from 75 in FY 2012 to 31 in FY 2015. This means an additional cost of $4,300 needs to be included in milling and resurfacing projects for deep patching with one-year delays in resurfacing. With extensive deep patching (37.7% of the wheel path), the deep patching costs ($24,505) are approximately 37% of the 1.5-in resurfacing costs in 2016. It is noted that traffic control for deep patching operation is not included in the cost estimate. The extensive deep patching can be a concern, since it may not be cost-effective to perform this much deep patching. In addition, the effectiveness of the resurfacing may be reduced because of the extensive deep patching. Some areas with less severe cracking (e.g., Load Cracking Severity Level 2) that were left without deep patching may, indeed, have cracks beyond the surface layer.

Table 6.4 COPACES Rating and Estimated Construction Costs

	11/20/2011	1/23/2012	11/26/2012	11/14/2013	10/15/2014		
COPACES Rating	74	65	57	36	31		
	12/6/2011	7/13/2012	3/20/2013	12/7/2013	7/18/2014	6/15/2015	2/20/2016
Milling & Resurfacing	$ 65,683	$ 65,683	$ 65,683	$ 65,683	$ 65,683	$ 65,683	$ 65,683
Deep Patching	$ 6,265	$ 8,387	$ 12,581	$ 13,288	$ 17,785	$ 18,593	$ 24,505
Total Construction Costs	$ 71,948	$74,070	$ 78,264	$ 78,971	$ 83,468	$ 84,276	$ 90,188

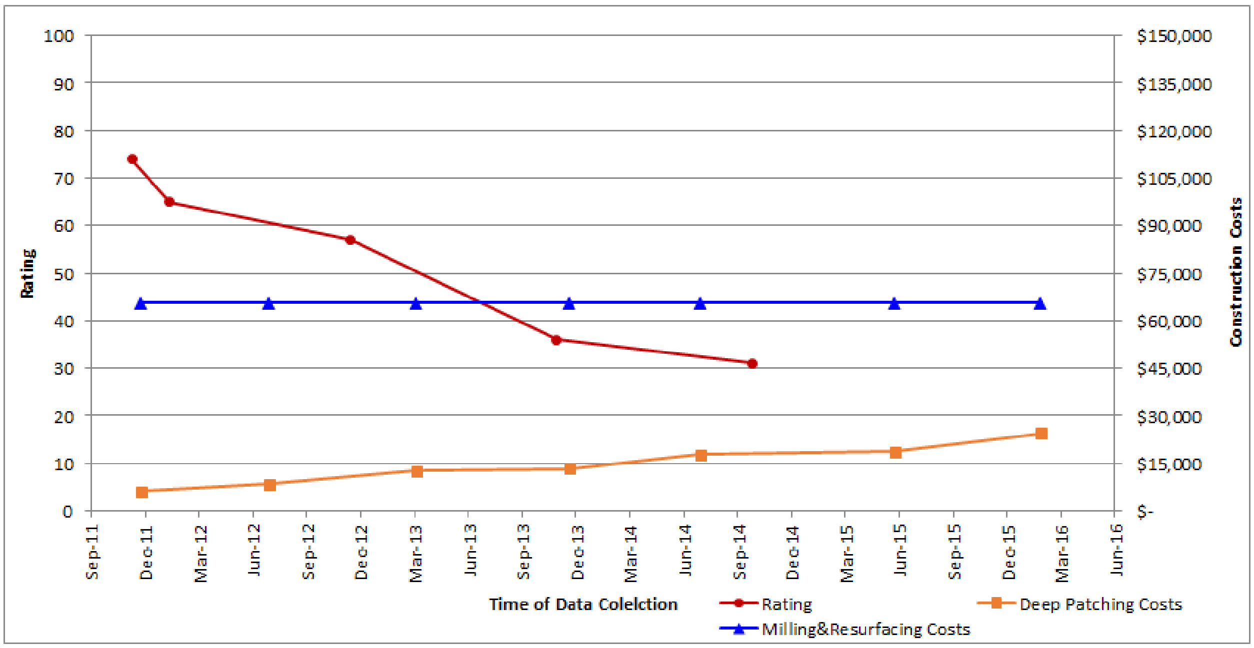


Figure 6.14 COPACES Rating and Construction Costs

6.3.4 Increased User Costs

As pavement resurfacing is delayed, surface distresses (e.g., severe rutting and potholes) continue deteriorating and lead to a rough ride, which causes an increase in the vehicle operating costs (VOC), fuel consumption, tire wear, vehicle repair and maintenance, and vehicle depreciation. In this study, the VOC is considered as the user cost. The models developed and calibrated by Michigan State University under NCHRP Project 1-45 (NCHRP, 2012) were adapted for computing the VOC cost based on the IRI. The process is briefly described as follows:

- IRI ratings are computed at 0.01-mile intervals using the 3D pavement data collected between 2011 and 2016. The small interval (0.01-mile) is to ensure that localized rough spots can be captured.
- The VOC is computed based on IRI at a speed of 55 mph using the VOC costs in Table 6.5 (NCHRP, 2012) and shows the effect of roughness on the VOC. In general, the VOC increases as IRI increase for all vehicle classes. VOC increases approximately 0.16 cents per mile when the IRI increases by 0.5 m/km, less than 3.5 m/km; it increases at a higher rate of 0.6 cents per mile when the IRI is greater than 3.5 m/km. The VOC for trucks is approximately 4 times of that of a passenger car, especially at locations with higher IRI. Therefore, the VOC is computed separately for both passenger cars and heavy trucks using Equation 1 (NCHRP, 2012). For example, the pavements with an AADT of 75,000, a truck percentage of 10%, and an IRI of 2 m/km would have a VOC of $613,638,000, which is computed by 75,000*356*(0.9)*(17.12 cents per mile) + 75,000*356*(0.1)*(70.08 cents per mile).

$$VOC = 365 * \text{Distance} \times \text{AADT} \times \sum_{i=1}^{3} (\text{Rate} \times \text{Price})_i$$

Table 6.5 Effect of roughness on VOC (source: NCHRP Report 720)

Speed	Vehicle Class	Total Vehicle Operating Costs per Vehicle (¢/mile)										
		IRI (m/km)										
		1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6
88 (km/h) or 55 (mph)	Medium car	16.8	16.96	17.12	17.28	17.44	17.6	18.08	18.72	19.2	19.84	20.48
	Van	20.16	20.16	20.32	20.32	20.48	20.64	21.12	21.6	22.24	23.04	23.68
	SUV	20.8	20.96	21.12	21.28	21.44	21.76	22.56	23.68	24.8	26.08	27.52
	Light Truck	34.88	35.04	35.2	35.2	35.36	35.68	36.64	37.76	39.04	40.32	41.76
	Heavy Truck	69.28	69.76	70.08	70.56	71.04	71.68	73.12	75.04	76.96	79.04	81.28
	Arti. Truck	90.4	90.88	91.52	92	92.64	93.44	95.2	97.28	99.36	101.76	104.16

The majority of the pavements have an IRI less than 2 m/km, which are considered as fair ride quality; higher IRI (e.g., greater than 2 m/km) can be observed at MP 10.5, MP 10.6, and MP 10.7. Table 6.6 lists the COPACES rating and VOC computed based on IRI. It is noted that VOC was not available for the data collected in late 2011 and 2014 because the IRI was not recorded. Figure 6.15 shows the VOC at different times. The VOC is approximately $1.3

million per lane mile per year, which is approximately 16 times of the construction cost. As the rating dropped from 60 to 36, on average, the VOC increased 0.2% ($3,300) per year. The VOC increased at a higher rate of $7,600 per year when the rating drops below 40. Overall, the additional user cost is slightly associated with a composite rating and, mostly importantly, associated with the type of distresses (e.g., potholes, severe rutting, etc.).

Table 6.6 Pavement Distress and Estimated Costs on S.R. 26

	11/20/2011	1/23/2012	11/26/2012	11/14/2013		
COPACES Rating	74	65	57	36		
	12/6/2011	7/13/2012	3/20/2013	12/7/2013	6/15/2015	2/20/2016
User Cost		$ 1,325,875	$ 1,330,294	$ 1,330,518	na	$ 1,347,443

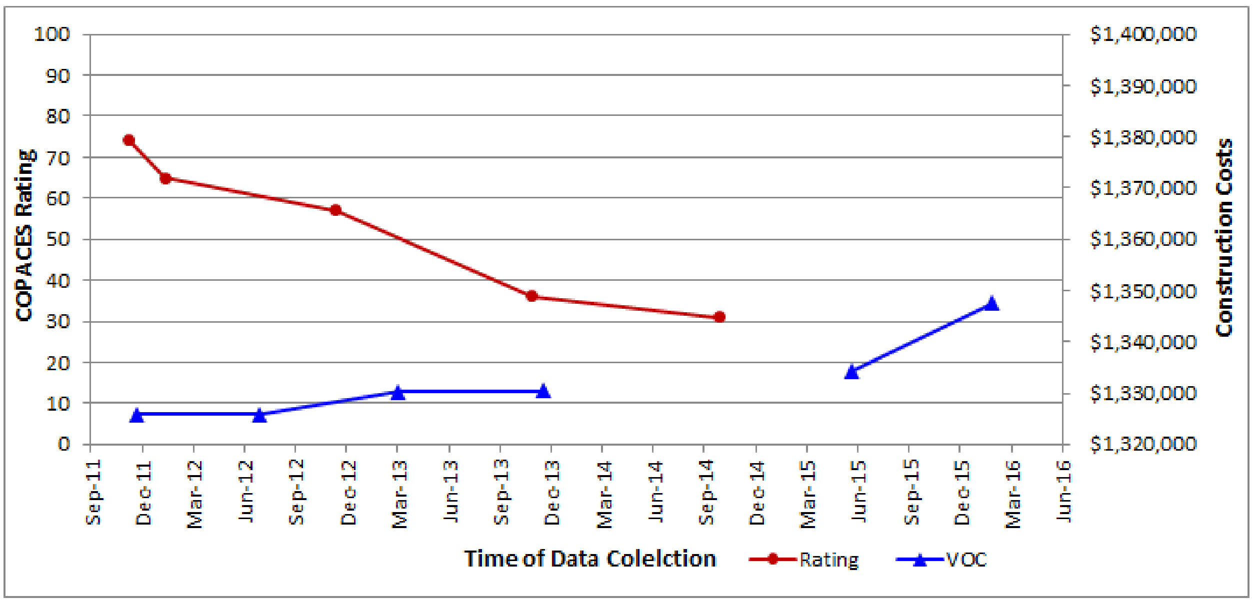


Figure 6.15 VOC at different times with different pavement delay conditions

6.4 Summary

The impacts the delayed resurfacing are 1) decreased pavement resurfacing effectiveness (e.g., reduced Pavement 70 Interval, 2) increased construction costs (e.g., increase of construction costs, such as patching, strip sealing, deep patching, etc.), and 3) increased user costs. Results are summarized as follows:

- Based on the selected projects with high traffic volume, the resurfacing effectiveness (Pavement 70 Interval) decreases more than 10% at every 5 points of COPACES rating when resurfacing is conducted at a rating lower than 70. Thus, it indicates resurfacing delay has significant impact on the reduced resurfacing effectiveness. More data, especially projects with different traffic volumes, are needed to support this finding.

- A case study was conducted on S.R. 26 near the Savannah Port to critically assess the construction costs and user costs caused by a pavement resurfacing delay (e.g., below a rating of 70). Results show the construction costs (additional construction costs for deep patches) increased steadily ($4,300 per lane-mile per year) as the overall pavement condition decreased based on the assumed 4-in deep patching from 2011 to 2016. It is noted that this cost does not include traffic control costs, which can be significant for night-time construction. There was a significant increase in the area requiring deep patching (29% to 38%) when the rating dropped from 40 in FY 2014 to 31 in FY 2015. This shows pavement deterioration occurs at an increasing rate in later stages; thus, it is critical not to defer pavement preservation too long. Preservation treatment applied before pavement reaches poor condition can cost-effectively extend the service interval without going to major rehabilitation.
- The user costs, i.e., VOC, was computed based IRI using the models developed under NCHRP 1-45. Results show that as the pavement condition (e.g., rating) deteriorated, the IRI increased slightly, which results in a small increase (0.2%) in the VOC. The user costs are approximately 16 times of the construction costs (including resurfacing and deep patching).
- The combined construction and user costs increased $40,000 (6%) per lane-mile per year. A significant increase can be observed in 2013 when the rating dropped below 50.
- In addition to the increase in the construction and user costs, the effectiveness or performance in the subsequent resurfacing cycle may be shortened because of the extensive deep patching and potential damage under the less distressed area. Therefore, continuously monitoring and studying the pavement performance on S.R. 26 after being resurfaced in 2016 is recommended to identify the right timing for resurfacing.
- Based on different roadways categorized by GDOT (Critical, High, Medium, and Low), different deterioration behaviors with year, time, and traffic characteristics, along with design categories, should be incorporated into the analysis to categorize the pavement deterioration behavior. Therefore, different resurfacing trigger timing/criteria can be

established based on their true behavior. In addition, the current GDOT policy uses a rating of 70 as a trigger point. With rich data, this trigger point can be further explored to define a refined resurfacing timing criteria with the factors of a composite rating, using structure/non-structure deducts, deterioration rates and GDOT's roadway categories to determine the right timing on different roadways (pavement designs).

7 CONCLUSIONS AND RECOMMENDATAIONS

The objectives of this research project are 1) to study the actual pavement performance of GDOT's resurfacing projects using GDOT's rich historical pavement condition evaluation data; 2) to study the pavement resurfacing delay situation; and 3) to study the impact of pavement resurfacing delay with a special focus on the effectiveness (or service interval) of pavement resurfacing and the increases of construction and user costs. For consistent performance measures, two types of pavement service intervals are studied in this project: "Pavement Resurfacing Interval," which represents the time period between two consecutive resurfacing activities, and "Pavement 70 Interval," which represents the time period for a newly resurfaced pavement to reach a rating of 70. Major findings are as follows:

Findings on Pavement Resurfacing Interval and Pavement 70 Interval:

1) The statistical analysis shows that the average Pavement Resurfacing Interval of the 370 high-quality resurfacing cycles is approximately 11.6 years. The average Pavement Resurfacing Interval varies by district, ranging from 10.3 years (District 6) to 12.2 years (District 5). It is noted that very few high-quality resurfacing cycles (2) are on interstate highways; thus, the findings based on the 370 resurfacing cycles may not represent the behavior on the interstate highways. Nor do the findings are for the critical, high, medium, and low priority routes based on GDOT's new route priority system.

2) Comparison of the pavement performance among different traffic-volume categories (e.g. high, medium, or low) shows a slight decline in the average Pavement Resurfacing Interval for the low traffic volume category (12 years to 11.2 years). There are no distinct differences because roadways with higher traffic volume have better pavement designs.

3) Study of Pavement Resurfacing Intervals by functional classes shows the Pavement Resurfacing Intervals for rural roads are shorter than urban roads (10.9 years vs. 11.6 years). The Pavement 70 Interval has a similar trend with shorter intervals, 9.6 years for rural roads and 10.6 years for urban roads. GDOT's resurfacing practices in urban/rural areas could play a key role. In addition, the difference in the pavement designs could also play a role.

4) The average Pavement 70 Interval of the 370 resurfacing cycles in this study is approximately 10.7 years; this is 0.9 years shorter than the average Pavement Resurfacing Interval. The average Pavement 70 Interval varies by district, ranging from 9 years (District 7) to 10.8 years (District 5). The shorter life in District 7 could potentially be due to its higher traffic volume.

5) Comparison of the pavement performance among different traffic volume categories (e.g. high, medium, or low) shows an average Pavement 70 Interval of 9.8 -10.7 years. The Pavement 70 Interval shows a slight decline when going from a medium traffic volume to a high traffic volume. This is similar to the trend observed in the Pavement Resurfacing Interval.

Findings on pavement distress characteristics:

6) Study of the distresses on the 370 high-quality resurfacing cycles in this study shows the predominant distresses are load cracking, block cracking, and rutting, which contribute to 46.7%, 35.1%, and 8.6% of the total deduct values, respectively.

7) Block cracking accounts for a higher percentage in the southern region (37.4%-39.1% in Districts 2, 4, and 5) than in the northern region (25.5%-32.0% in Districts 1, 6, and 7). This may be because of the underlying concrete pavement, base type (e.g., soil cement), soil type, etc.

8) The average rutting deduct is 2.9, which corresponds to an average rut depth less than ¼-in. This indicates that rutting is not a major concern for triggering resurfacing after the improvements in pavement materials and structural designs.

9) Preliminary study using selected resurfacing cycles (32) shows load cracking Severity Level 1 is first reported in the first 2-4 years after resurfacing. The extent increases 3% per year in the first 5 years and 5% per year in the next 5-9 years. Load cracking Severity Level 2 is reported around the 6th year, and the extent grows at a slow rate (2% per year). Only a few resurfacing cycles were reported with Severity Level 3.

10) Among the 32 resurfacing cycles, the majority of block cracking is rated at Severity Level 1. It is first reported 2-3 years after resurfacing and continues to grow linearly at

a rate of 5% per year. An average of 55% of block cracking Severity Level 1 is reported in the 12th year.

11) The high-quality resurfacing cycles were mapped and categorized by Pavement 70 Interval, and AADT illustrates the capability of GIS to display spatial data, which is more intuitive and informative to decision-makers than non-spatial data. With more high-quality resurfacing cycles available in the future, more in-depth spatial analysis can be performed to analyze pavement performance and corresponding geospatial parameters.

Findings on pavement resurfacing delay condition:

12) The average RBR of the 370 high-quality resurfacing cycles is approximately 64.8. Historically, approximately 51% of resurfacing cycles have been delayed for more than one year. Among them, 7% were treated at a rating less than 55. District 4 has the highest RBR, which might imply that District 4 has a more timely resurfacing practice than other districts.

13) The analysis of composite rating shows a consistent and rapid decline since FY2002. The composite rating dropped from 88.4 in FY2002 to 79.8 in FY 2014 and has not been able to meet the network performance goal of 85 since FY 2007. Not only did the resurfacing delay (i.e., pavement with a rating less than 70) increase significantly from 18% in 2010 to 25% in 2014, but also there is an increase in the projects in bad condition (e.g., a rating less than 55), which may require more expensive treatment. Adequate funding and proper programming are needed for achieving the performance goal (i.e., a composite rating of 85) at the network level.

14) In 2014, approximately 24% (approximately 4,691 surveyed miles) of pavements had a rating less than 70, which were due or past due for resurfacing. These included 139 surveyed miles on interstate highways and 4,552 on non-interstate highways. Districts 6 and 7 have the largest resurfacing delay of 64 and 50 surveyed miles on interstates; District 4 has the largest resurfacing delay of 1,174 surveyed miles on non-interstate highways.

Findings on consequences of delayed resurfacing:

15) Study of pavement RBR and Pavement 70 Interval shows a slight decrease in the pavement life as the RBR decreases (i.e., 0.2 years per point). However, with a small R^2 (0.2) and widespread variations in pavement lives, this relationship cannot be proved to be statistically significant.

16) Study of selected resurfacing cycles with high traffic volume shows the resurfacing effectiveness (Pavement 70 Interval) decreases more than 10% (1 year) at every 5-point drop of COPACES rating when resurfacing is conducted at a rating less than 70. Results indicate the resurfacing delay has significant negative impact on resurfacing effectiveness. More data, especially projects with different traffic volumes, are needed to support this finding.

17) A case study was conducted on S.R. 26/U.S. 80 in Chatham County (near the Port of Savannah) using the data collected by Ga Tech's sensing van between 2011 and 2016 to provide consistent and quantitative assessment on the increased construction costs and user costs caused by a pavement resurfacing delay. Results show, on average, that deep patching costs increased approximately $4,300 per lane-mile per year when the rating dropped from 75 in FY 2012 to 31 in FY 2015. This means an additional cost of $4,300 needs to be included in milling and resurfacing projects for deep patching with one-year delays in resurfacing. With extensive deep patching (37.7% of the wheel path), the deep patching costs ($24,505) are approximately 37% of the 1.5-in resurfacing costs in 2016. The performance of the subsequent resurfacing cycle may be reduced with the extensive patching. In addition, maintenance activities, such as patching potholes and spot overlay prior to resurfacing, are needed to address safety concerns and maintain the expected level of service. This will increase the work load on a limited number of maintenance crews. These all indicate the importance and cost effectiveness of timely performing the necessary rehabilitation.

18) The user costs, computed as Vehicle Operating Cost (VOC) based on International Roughness Index (IRI), increased by approximately 0.2% ($2,400) per year as the

COPACES rating dropped from 75 in FY 2012 to 31 in FY 2015. There was a significant increase (1%; $13,000) from FY 2015 to FY 2016. The user cost is 16 times the construction cost, which includes deep patching, and milling and resurfacing.

19) Historical COPACES data on S.R. 26 shows the rating dropped rapidly (more than 10 points per year) from 65 in FY 2012 to 31 in FY 2015. It shows pavement deterioration occurs at an increasing rate in the later stages; thus, it is critical not to defer pavement preservation for too long. With the rapid deterioration, the timing or opportunity for pavement preservation can be missed, especially with bi-annual surveys, and much more expensive rehabilitation would be needed.

To further study the pavement service interval/deterioration in Georgia, the following need to be considered:

1) Interstate highways are a significant capital investment; however, limited interstate pavement condition data have been collected due to safety concerns. There is a need to develop an automated method using computer vision and/or laser technology to collect pavement condition data on Georgia's interstate highways. Safety and technology should be focused upon when acquiring more and better data for the interstate highways.
2) GDOT is in the process of implementing a new route priority system (critical, high, medium, and low priority) based on traffic volume, functionality, etc. As the pavement design, traffic load, and required level of service for each category can be different, there is a need to develop a resurfacing strategy for each category based on its actual deterioration behaviors.
3) The long-life pavements, especially pavements with multiple cycles, could be further studied to identify the factors (e.g. timely pavement preservation for pavements with specific base materials, traffic volumes, and designs) contributing to the extended pavement service interval. The pavements that last perpetually by only applying resurfacing on a timely basis could be studied to determine the maximum number of resurfacing cycles that could be achieved practically.
4) To get a quantitative assessment of the reduced resurfacing effectiveness caused by pavement resurfacing delay, it is recommended that long-term performance monitoring be continued on S.R. 26 after its recent delayed milling and resurfacing.

5) Besides a composite rating, further study is needed to identity additional indicators, like load-induced distresses, deterioration rates, etc., that can be used to more adequately refine GDOT's current treatment criteria and timing (the performance indicators, like COAPCES ratings, and the threshold, like 70).

6) Additional variables, such as the pavement structure design, materials, subgrade, environments, and ESAL are recommended for inclusion in future performance studies to gain in-depth understanding of the factors impacting pavement performance, even though these data are difficult to obtain.

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APPENDIX I: RULES FOR DETERMINING PAVEMENT SERVICE INTERVAL WITH A CONFIDENCE LEVEL

The rules for determining the pavement life, including Pavement Resurfacing Interval and Pavement 70 Interval, with a confidence level are summarized in the following tables.

Table I-1 Pavement Project Data Evaluation Decision Rules for Pavement Life (Life-Resurf)

Pavement Life: (Life-Resurf)	**Definition:** The time period from the establishment of a new pavement surface (with a typical project rating of 100(105)) until the next pavement reconstruction/resurfacing (with a typical project rating of 100(105)). (From **Yr-Start** until **Yr-EndResurf**, respectively.)
Lowest level Rule:	**Rule:** If the project contains no **U** or **N/A** or **I** confidence levels, then, the overall Pavement Life confidence level is selected as the lowest confidence level (**Low, Medium or High**) of these three factors: 1. **Yr-Start*** 2. **Yr-EndResurf** * 3. **Trend in the middle*** *These factors and their related confidence levels will be defined in the tables that follow.
Factor Confidence Rating Definitions and applications to Pavement Life:	
I	**I**: (Incomplete) The **I** rating means that the project data for these projects is incomplete. If any of the three decision factor ratings is **I,** with no **U** or **N/A**, the overall level is **I**.

Table I-2 Pavement Project Data Evaluation Decision Rules for Year Start (Yr-Start)

Year Start: (Yr-Start)	**Definition:** The **Year Start** is the beginning of a pavement life, and typically is identified by the first project rating of 100 (105) for the best pavement cycle trend which is selected. When the rating of 100 (105) is not indicated, a **Year Start** will be established according to the rules given with the confidence levels below.
Factor Confidence Rating Definitions and applications to Year Start:	
High	**High:** A high confidence level for the **Year Start** is indicated by a project rating of 100 or 105 at the beginning of the selected pavement cycle trend. Sometimes the COPACES surveyors used a project rating of 105 to identify the project as being under construction at the time of survey. For project data with more than 2 project ratings of 100 (or 105) in subsequent years, the **Year Start** is selected as the year of the second 100 (or 105) from the right.
Medium	**Medium:** A Medium confidence level for the **Year Start** is indicated where the highest rating at the beginning of the selected pavement cycle trend falls between 90 and 100 and one of the following conditions apply: • Support data (additional ratings in the same year) is surveyed by more than one additional GDOT office (generally the District Office and/or the General Office) within a 4-year period before the high rating point. Then, the year following the year of the support data will be considered as the **Year Start**. • Support data (additional rating(s) in the same year) is surveyed by at least one GDOT office (generally the District Office or the General Office) within a 2-year period before the high rating point. The rating of the Support data must be at least 20 points lower than the rating of the highest rating point. Then, if the support data is the year before the highest point, the highest point will be considered as the **Year Start**. If the support data is two years before the highest point, the year before the highest point will be considered as the **Year Start**. In the case with no support data or where the support data occurs more than 2 years before, where the rating of the highest point of the beginning of the trend is between 95 and 100, the trend can be extrapolated backwards for one year. If this extrapolated point has a rating of 100 or higher, this point will establish the **Year Start** with a **Medium** confidence rating. The **Year Start** cannot overlap any previous trend data.
Low	**Low:** A Low confidence level for the **Year Start** is indicated where the rating data was collected in 1987 or earlier and the highest rating point is higher than 90 but less than 100. In this case, 1986 will be considered as the **Year Start**. In any case after 1987 without support data, where the rating of the highest point at the beginning of the trend is between 90 and 100, the trend can be extrapolated backwards for two years. If this extrapolated point has a rating of 100 or higher, this point will establish the **Year Start** with a Low confidence rating. Otherwise, for this case, the **Year Start** will be **U**-uncertain at the extrapolated point. The **Year Start** cannot overlap any previous trend data.
I	**I**: An **I** (Incomplete) confidence level for the **Year Start** is indicated where the project data is considered too incomplete to create a **Year Start**.

Table I-3 Pavement Project Data Evaluation Decision Rules for Trend in the Middle

Trend in the middle	**Definition:** The **Trend in the middle** are the data points and associated straight-line defined from the time period from the establishment of a new pavement surface (with a typical project rating of 100(105)) until the next pavement reconstruction/resurfacing (with a typical project rating of 100(105)). (i.e., from **Yr-Start** until **Yr-EndResurf**) The **Trend in the middle** is selected as the best identifiable trend in the project survey history. In order to define the **Trend in the Middle** graphically, a straight line will be drawn between the known points (**Yr-Start** and the year before **Yr-EndResurf)** if available. If only one known end point is available, a combination of the known point and a weighted line position can be used. If both end points are unavailable, a weighted line position will be used. In the year before the Yr-EndResurf, if multiple points exist, the point defining the end of the trend line (for the Trend in the Middle) will be selected as the point which best supports the rest of the trend line.
Factor Confidence Rating Definitions and applications to Trend in the middle:	
High	**High:** A high confidence level for the **Trend in the middle** is indicated by reasonable and sufficient data including more than 5 project rating points or more than half of the data points between the year after the **Year Start** point and the **Year End** point. (Whichever number is higher.) The trend must look reasonable in the selected life cycle.
Medium	**Medium:** A medium confidence level for the **Trend in the middle** is indicated by reasonable and sufficient data with five data points or at least half of the data points between the year after the **Year Start** point and **Year End** point. (Which ever number is greater.) The trend must look reasonable in the selected life cycle.
Low	**Low:** A low confidence level for the **Trend in the middle** is indicated by a minimum of four data points or one less than half of the data points between the year after the **Year Start** point and **Year End** point. (Which ever number of points is greater.) The trend looks somewhat reasonable in the selected life cycle.
I	**I**: An **I** (Incomplete) confidence level for the **Trend in the middle** is indicated where the end year for the selected trend is incomplete and the rating on year 2007 is not surveyed by more than one office.

Table I-4 Pavement Project Data Evaluation Decision Rules for Year End (Yr-EndResurf)

<table>
<tr><td>Year End (Yr-EndResurf)</td><td>Definition: The Year End is the end of a pavement life. The Year End will be established according to the rules given with the confidence levels given below.</td></tr>
<tr><td colspan="2">Factor Confidence Rating Definitions and applications to Year End:</td></tr>
<tr><td>High</td><td>High: A high confidence level for the Year End is indicated by a project rating of 100 or 105 for the next life cycle within 3 years after the best pavement cycle trend.</td></tr>
<tr><td>Medium</td><td>Medium: A Medium confidence level for the Year End is indicated where the highest rating at the beginning of the next pavement cycle trend falls between 100 and 90 and one of the following conditions apply:
Support data (additional ratings in the same year) is surveyed by more than one additional GDOT office (generally the District Office and/or the General Office) within a 4-year period before the high rating point. Then, the year following the year of the support data will be considered as the Year End.
Support data (additional rating(s) in the same year) is surveyed by at least one additional GDOT office (generally the District Office or the General Office) within a 2-year period before the high rating point. The rating of the Support data must be at least 20 points lower than the rating of the highest point. Then, the year right before the highest point will be considered as the Year End.
Regardless of support data at the end of the trend, if the rating of the most appropriate end point is below 70, the year after the end point will be taken as the Year End with a Medium confidence level.
Regardless of support data at the end of the trend, if the end point rating is above 70, the best pavement cycle trend can be extrapolated for one year to cross the 70 project rating level. The point closest to the crossing will be the 70_year and the next year will be the Year End with a Medium confidence level. No overlaps into the next cycle are allowed.</td></tr>
<tr><td>Low</td><td>Low: Where there is no support data and the end point rating is above 70, the best pavement cycle trend can be extrapolated for two years to cross the 70 project rating level. The point closest to the crossing will be the 70_year and the next year will be the Year End with a Low confidence level.</td></tr>
<tr><td>I</td><td>I: An I (Incomplete) confidence level for the Year End is indicated where the best pavement cycle trend does not have a rating in year 2007 but still has a project rating in year 2006 with adequate trend supporting data.</td></tr>
</table>

Table I-5 Pavement Project Data Evaluation Decision Rules for Pavement Life to 70 rating (70_Life)

<table>
<tr><td>Pavement Life to 70: (70_Life)</td><td>Definition: The time period from the establishment of a new pavement surface (with a typical project rating of 100(105)) until the pavement deteriorates to a rating of 70. (From Yr-Start until 70_Yr) (An extension of up to one year may be considered for 70_Life due to the decision lag period of GDOT.)</td></tr>
<tr><td>Lowest level Rule:</td><td>Rule: If the project contains no U or N/A or I confidence levels, then, the overall Pavement Life to 70 confidence level is selected as the lowest confidence level (Low, Medium or High) of these three factors:
1. Yr-Start*
2. 70_YR *
3. Trend in the middle*
*These factors and their related confidence levels will be defined in the tables that follow.</td></tr>
<tr><td colspan="2">Factor Confidence Rating Definitions and applications to Pavement Life to 70:</td></tr>
<tr><td>I</td><td>I: (Incomplete) The I rating means that the project data for these projects is incomplete. If any of the three decision factor ratings is I, with no U or N/A, the overall level is I.</td></tr>
</table>

Table I-6 Pavement Project Data Evaluation Decision Rules for 70_YR

70_YR	**Definition: The 70_Year** is the end of the **Pavement Life of 70** and is determined as the year on the point at the 70 rating or the year closest to the location of the intersection of the trend line and a horizontal line established at the 70 project rating level. Confidence levels and rules for 7**0_YR** are given below.
Factor Confidence Rating Definitions and applications to 70_YR:	
High	**High:** A high confidence level for the **70_YR** is indicated by the point at the 70 rating or on the best pavement cycle trend (with a **Trend in the Middle** confidence of High) crossing at the 70 project rating level.
Medium	**Medium:** A medium confidence level for the **70_YR** is indicated if the best pavement cycle trend (with a **Trend in the Middle** confidence of Medium) crossing at the 70 project rating level or the trend line can be extrapolated for one year to cross the 70 project rating level.
Low	**Low:** A low confidence level for the **70_YR** is indicated if the best pavement cycle trend (with a **Trend in the Middle** confidence of Low) crossing at the 70 project rating level or the trend line can be extrapolated for two years to cross the 70 project rating level.
I	**I:** An **I** (Incomplete) confidence level for the **70_YR** is indicated if the best pavement cycle trend does not cross the 70 project rating level but the rating data is complete up to year 2007.

Table I-7 Pavement Project Data Evaluation Decision Rules for RBR

RBR (RBR)	**Definition:** The **RBR-** RBR is generally established as the rating of the year before the year end. It may be a point on the trend line or it may represent the rating created by the intersection of a vertical year line and the trend line. The confidence levels and rules for **RBR** are given below.
Factor Confidence Rating:	**Factor Confidence Rating Definitions and applications to RBR:**
High	**High:** A high confidence level for **RBR** is indicated by a point or where the rating is created by the trend line intersection and the **Trend in the Middle** has a high rating.
Medium	**Medium:** A medium confidence level for the **RBR** with no support data is indicated where the rating is created by the trend line intersection and the **Trend in the Middle** has a medium rating.
Low	**Low:** A low confidence level for the **RBR** is created by the trend line intersection and the **Trend in the Middle** has a low rating.
I	**I:** An **I** (Incomplete) confidence level for the **RBR** is indicated if the Year End is rated as incomplete.