# MULTI-YEAR PAVEMENT REHABILITATION NEED ANALYSIS

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## ABSTRACT

It is crucial for transportation agencies to determine funding needed for maintaining their pavement systems at a desirable level of performance. A consistent and transparent multi-year pavement rehabilitation need analysis would serve a vital role for planning and for funding justification. A multi-year pavement rehabilitation need analysis system was developed for and implemented by the Georgia Department of Transportation (GDOT) to conduct analyses for such purposes. This system integrates network level requirements, such as acceptable statewide pavement performance composite rating, with project level actions on when, where, and what to treat pavement projects. The analysis performed by the system can take into account various requirements and constraints, such as to achieve certain pavement performance level and to balance the funding or pavement performance among GDOT Engineering Districts and the State Congressional Districts. Examples of determining 5 years (2003-2007) pavement rehabilitation funding needs based on different requirements for GDOT are presented. The analyses were based on the actual year 2002 GDOT statewide pavement condition survey data. The benefits of the proposed system are summarized, and the recommendations for future research are also discussed.

## KEY WORDS

PAVEMENT / MULTI-YEAR / NETWORK / PROJECT SELECTION / NEED ANALYSIS

## 1. INTRODUCTION

The Georgia Department of Transportation (GDOT) has maintained its pavement network in very good condition; the pavement condition has been rated as being one of the best in the USA for the past few years. However, due to the limited budget, it has become increasingly challenging to continuously maintain the pavement condition at its present level. It has become more difficult for GDOT to obtain adequate funding from the state legislature for maintaining the adequate performance for the highway system. The GDOT is looking for a system that can perform multi-year pavement maintenance, repair and rehabilitation (MR&R) need analysis based on the current and past statewide pavement performance data (GDOT, 1990) to identify minimal funding needed to maintain the highway system at a desirable level of service, and to simulate and predict long term pavement performance consequences under different funding scenarios. In addition, a system, which could perform scenario analyses subject to certain constraints, such as balancing funding allocated to all GDOT Engineering Districts and the State Congressional Districts, would be highly desirable. The system presented in this paper incorporates various functions to address the various needs mentioned above. These needs have also been the trends for developing the pavement management systems (Kulkarni & Miller, 2003; Wang, et al, 2003; Ferreira, et al, 2001; Chan, et al, 1994). Although the system was designed for GDOT to develop multi-year MR&R plans, it is general enough that with slight modifications the system could be used by other transportation agencies.

The paper is organized as following. The current GDOT annual pavement maintenance and rehabilitation planning practice is presented first in the following section. The proposed multi-year pavement rehabilitation need analysis system is then presented. After the system is introduced, examples of using the year 2002 statewide pavement condition evaluation data for determining the next five years statewide pavement MR&R plans subject to different performance requirements and balancing constraints are presented. The examples show the importance and value of having multi-year highway pavement rehabilitation needs analysis system. Finally the conclusions are summarized and future research needs are recommended.

## 2. CURRENT PAVEMENT MAINTENANCE MANAGEMENT PRACTICE IN GDOT

The GDOT had been maintaining its 28,960-centerline-km (18,000 miles) highway pavement system effectively using the pavement maintenance and rehabilitation planning procedures described below.

1) Perform pavement condition evaluations annually, using the Pavement Condition Evaluation System (PACES) developed by GDOT from 1986 to 1997, and using the Computerized Pavement Condition Evaluation System (COPACES) implemented in 1998. PACES and COPACES were designed to evaluate the severity and extent of various types of pavement surface distresses at the time the survey was made. Pavement performance ratings based on the distress conditions were then calculated.
2) Projects with unacceptable conditions (low performance ratings) are prioritized for MR&R treatments. GDOT Engineering District Offices are responsible for making initial selections of MR&R projects. Suitable MR&R treatment methods for candidate projects are determined by the engineers based on the pavement distress conditions, performance ratings, and traffic conditions.
3) The Central Office (Office of Maintenance of GDOT) collects the lists of the projects submitted from all seven Engineering District Offices and develops the statewide yearly pavement rehabilitation program. The total number of projects selected for MR&R is determined based on funding availability and other considerations, such as balancing funding distribution among different GDOT Engineering Districts and State Congressional Districts. Additionally, MR&R projects are scheduled based on contractors' workloads.

PACES was designed to record the severity and extent of various types of surface defects of asphalt pavements at the time a field survey was performed, primarily via visual observations. The only instrument used is the rut-depth gauge for measuring rutting over 0.6 cm (¼ in.). During the field survey, the extent and severity of each type of distress occurring in the 30-m (100-ft) sampling section are identified and recorded to represent the distress conditions of each segment. Based on the survey results in each segment of the project, a composite project rating is then calculated. The following are the types of distress recognized by PACES:

- rut depth
- block cracking
- patches/potholes
- edge distress
- corrugations/pushing
- load cracking
- reflective cracking
- raveling
- bleeding/flushing
- loss of section

Each type of distress is further classified into different levels of severity. The statewide pavement condition evaluation is performed to record the extent of the various distress types at different severity levels for all the pavement projects. The general procedure in implementing PACES was described by Tsai and Lai (2001, 2002). The detailed procedure for distress identification is presented in the *Road Surface Management Manual* (GDOT, 1990). Results of the pavement field evaluation, such as project ratings and the distresses are then used for determining proper pavement rehabilitation treatment strategies and treatment prioritization.

The procedure described above has been used by GDOT since the late 1980's for managing the state highway system with reasonably good results. However, GDOT was aware of certain inherent deficiencies of the existing practices and the need for improvements, particularly with the advent of information technologies. For prioritizing pavement MR&R projects as described in steps 2 and 3 above, GDOT recognized that it needed to develop a system that could perform tasks more efficiently, incorporate more consistent decision criteria, satisfy various specified requirements, utilize accumulated historical pavement survey data, and have the ability to maximize the pavement performance at the network level subject to different balancing constraints.

## 3. IT-BASED MULTI-YEAR PAVEMENT REHABILITATION NEED ANALYSIS SYSTEM

The IT-based multi-year pavement rehabilitation need analysis system was developed based on the needs stated above. The system consists mainly of two modules: project-level analysis module and network-level analysis module, as shown in Figure 1. The Client/Server-based system allows District Offices to communicate with the Central Office through the shared Central Database. Oracle 8i was used to develop the centralized databases. The client/server communication is through TCP/IP protocol. MS Excel 2000 was used to generate graphs and reports, and MS Visual Basic 6.0 was used to develop the functions and user friendly interfaces. The system can operate on Windows 95/98/ME/NT/2000/XP.

Important considerations in the design of the systems were (1) compatibility with the current practices used by GDOT to minimize the efforts of migrating from the old practice to the new system; (2) direct linkage between network-level analysis results and project-level maintenance plans; (3) capability to balance needs among GDOT Engineering Districts and State Congressional Districts; (4) flexibility to incorporate new developments in pavement performance models and new treatment method decision criteria; (5) flexibility to modify existing models, treatment methods, boundaries of GDOT Engineering Districts and State Congressional Districts; (6) easy provision for feedback so that the engineers would know not only the maintenance plans but also the impact of the maintenance plans and the influence of past maintenance activities on future pavement performance; (7) capability to perform "What If" analyses so that the decision maker can compare results of different scenarios.

## 4. PROJECT LEVEL ANALYSIS MODULE

The objectives of this module are to determine appropriate MR&R method and associated costs, predict future project performance, and calculate life-cycle cost effectiveness ratio for each pavement project within the network. Three important functions were used to develop project-level analysis module: Project MR&R Method and Cost Determination Function, Pavement Performance Forecasting Function, and Life-Cycle Cost Effectiveness Analysis Function, as shown in Figure 1.

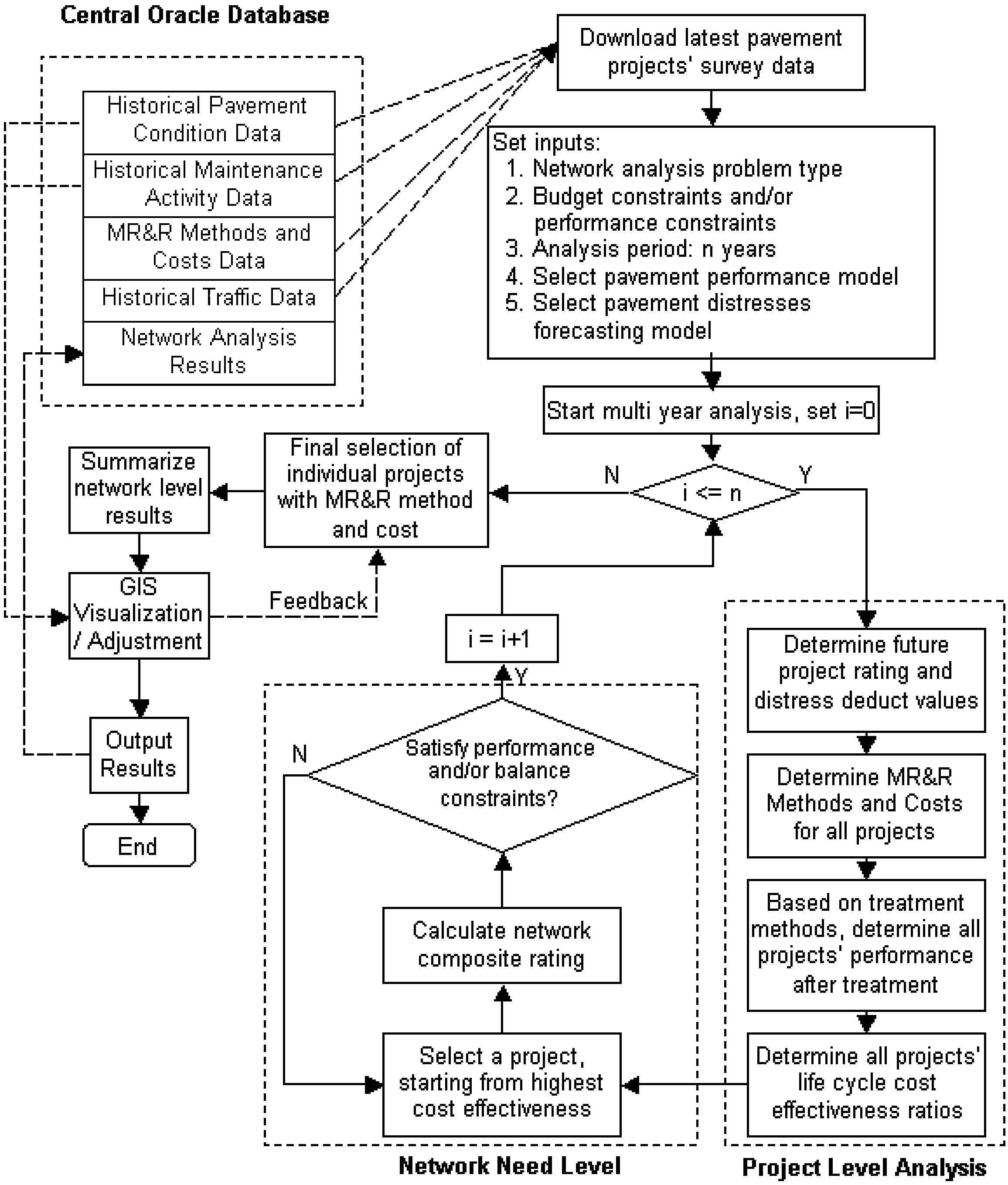
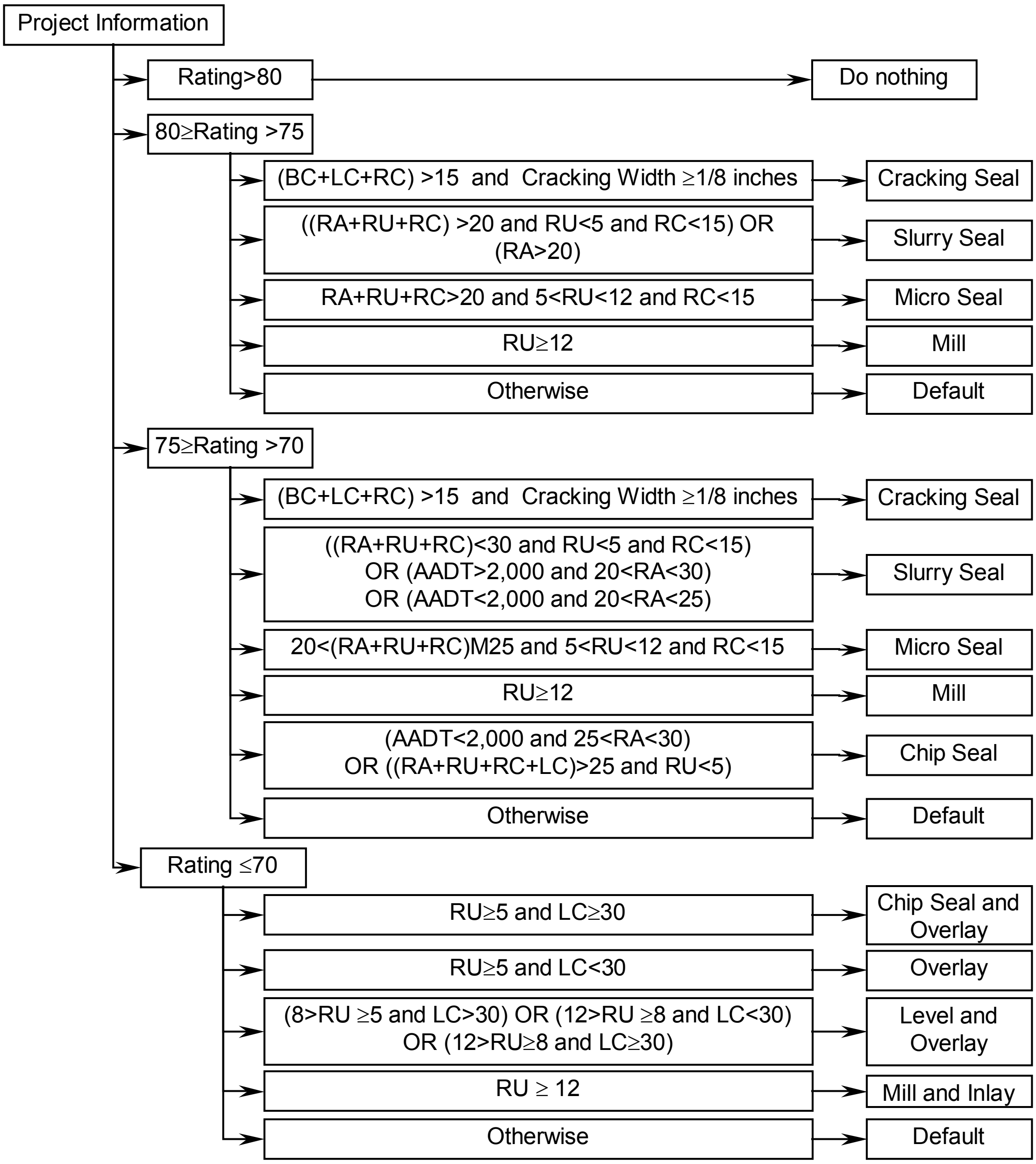



Figure 1: Multi-Year Pavement Rehabilitation Need Analysis System

## 4.1. Project MR&R Method and Cost Determination Function

The determination of an appropriate MR&R method for a pavement project was developed based on the current GDOT practices. This function determines a MR&R treatment method for each project from 9 different MR&R treatment methods currently used by GDOT, based on the predicted pavement performance rating and pavement distress conditions as shown in Figure 2. Once an appropriate MR&R method for a pavement project is determined, the associated MR&R cost for the project can be calculated based on the unit cost of the selected MR&R method and the lane-miles of the project. Information related to MR&R treatment methods and unit costs is stored and can be updated in the central database. In order to determine the future MR&R method for a project, it is crucial to have the predicted pavement performance rating and distress conditions at the project level as shown in Figure 2.




BC: Blocking cracking deduct value; LC: Load cracking deduct value;
RC: Reflective cracking deduct value; RA: Raveling deduct value; RU: Rutting deduct value

Figure 2: Decision Tree of Project MR&R Treatment Methods

## 4.2. Pavement Performance Forecasting Function

In order to compute future pavement rating and distress condition (i.e. distress deduct values), two analyses were performed. The first one was to predict pavement performance ratings (a value from 0 to 100, with 100 representing the best condition) and the other was to predict pavement distress deduct values. The distress deduct value for a specific pavement distress type and severity level has a value from 0 to 100, reflecting the extent of the specific pavement distress conditions. Two separate analyses were conducted is because the project rating is obtained based on the sum of all distresses and it has a clear increase and decrease trend. However, the project distress conditions were measured based on the type, severity level, and extent of distresses and it does not have a clear increase or decrease trend because one distress type and severity level may be migrated into the others in the course of distress propagation. The project rating is computed on a linear regression model using the latest 3 years' ratings which we found it provide the most accurate forecast results. The project distress deduct values were obtained based on the expected deduct values of various distresses for a given rating that were determined statistically based on historical data.

### 4.3. Life-Cycle Cost Effectiveness Analysis Function

The concept of life-cycle cost effectiveness was used in developing this function and was used for prioritizing pavement projects for MR&R. The cost effectiveness in this paper is defined as the ratio of averaged annual performance rating improvement to the annualized pavement construction costs for a pavement project. The annual pavement performance improvement considers the rating difference between the scenario of applying a given MR&R action and the scenario of applying no MR&R. The annualized pavement construction costs for a pavement project are calculated by taking into account the annual interest rate (Tilly, 1997; Vassie, 1997*).*

## 5. NETWORK LEVEL NEED ANALYSIS MODULE

The objective of this module is to analyze multi-year MR&R needs and determine optimum MR&R plans at the network level based on the information provided from the Project-Level Analysis Module. The module could perform two types of analyses with each analysis further subject to certain network level constraints. Type I is to determine the least future budget needed based on certain pavement performance constraints, and Type II is to determine optimum future pavement MR&R plans based on budgets availability constraints. Five different balancing constraints could be imposed in for either one of the analyses listed above. These five balancing constraints are: (1) no balance constraint; (2) balance pavement performance among GDOT Engineering Districts; (3) balance pavement performance among State Congressional Districts; (4) balance MR&R cost among GDOT Engineering Districts; and (5) balance MR&R cost among State Congressional Districts.

The network level (district network level, or statewide network level) pavement performance composite rating is one of the essential parameters in the network analysis module. The composite rating is the average rating weighed by project length in lane-miles of all the pavement projects within the specified network boundaries and is calculated by the following formula:

$$\text{Composite Rating} = \frac{\sum_{i=1}^{\text{Total No. of Projects}} (\text{Project Length in LaneMile})_i \cdot \text{Project Rating}_i}{\sum_{i=1}^{\text{Total No. of Projects}} (\text{Project Length in LaneMile})_i}$$

The user could set two types of pavement performance requirements: minimum individual pavement project rating and minimum network-level composite rating. The first requirement allows individual project with performance rating below the threshold value to be treated first; the second requirement ensures the overall pavement conditions in the network reaches the prescribed performance level. Based on the user-selected balancing criteria and performance requirements described above, this module will perform the analysis and provide a MR&R plan for each year including the funding required and a list of projects to be treated with appropriate treatment methods.

## 6. CASE STUDIES

In fiscal year 2002, 2,119 projects were surveyed by GDOT covering lane length of 58,496 kilometers (36,348 lane miles) of state highway. This data set was used to perform the future five-year (2003 to 2007) pavement need analysis. Five cases of pavement need analysis were conducted, and the five-year average composite rating for each case was computed to compare the effectiveness of different funding plans. Using a 1.1 GHz Pentium IV computer, it took about 1 hour and 15 minutes to run the five cases shown in Table 1. The computation time required to perform the analyses is reasonably fast which makes it feasible for the user to perform “What-if” analyses of various rehabilitation plans.

Table 1 Results of Cases Study

| Year | Case 1 | | Case 2 | | Case 3 | | Case 4 | | Case 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Cost | SCR | Cost | SCR | Cost | SCR | Cost | SCR | Cost | SCR |
| Current | 0.00 | 87.84 | 0.00 | 87.84 | 0.00 | 87.84 | 0.00 | 87.84 | 0.00 | 87.84 |
| 2003 | 0.00 | 85.15 | 65.77 | 87.48 | 95.02 | 88.44 | 65.21 | 87.49 | 144.20 | 90.00 |
| 2004 | 68.42 | 85.00 | 65.31 | 86.94 | 84.04 | 88.32 | 65.24 | 86.88 | 116.4 | 90.01 |
| 2005 | 79.22 | 85.01 | 65.35 | 86.15 | 79.12 | 87.57 | 65.41 | 86.09 | 176.87 | 90.00 |
| 2006 | 83.81 | 85.01 | 65.77 | 85.22 | 69.22 | 86.20 | 65.86 | 85.17 | 282.43 | 90.01 |
| 2007 | 94.92 | 85.00 | 65.20 | 83.98 | 0.00 | 83.30 | 65.25 | 83.99 | 366.36 | 89.94 |
| Avg. | 65.27 | 85.03 | 65.48 | 85.95 | 65.48 | 86.77 | 65.39 | 85.92 | 227.36 | 90.00 |

Notes: Unit of Cost: Million Dollar; SCR: Statewide Composite Rating

Case 1: Obtain minimal funding needed for each year to achieve the minimum statewide pavement performance composite rating of 85 for each year. It was found that a total of $326.37 million dollars for the five years period is needed.

Case 2: Determine the composite rating for each year if the five-year minimal funding obtained in Case 1 ($326.37 million dollars) was evenly distributed yearly in the coming 5 years. The average composite rating for 5 years became 85.95. Although the overall five-year average composite rating in this case was better than the one in Case 1, the pavement performance in Fiscal Year 2007, 83.98, does not reach the acceptable level.

Case 3: Reverse the yearly funding utilization plan as shown in Case 1. The average composite rating for 5 years was 86.77, which was significantly higher than Case 1; however, the pavement performance in Fiscal Year 2007, 83.30, does not reach the acceptable level.

Case 4: Case 4 is similar to Case 2, except Case 4 considered the constraint of balancing pavement performance among seven GDOT Engineering Districts. The average composite rating for 5 years was 85.92, which is slightly lower than Case 2, the one without considering balancing the funding in each engineering district. The district level pavement performance rating distributions among the 7 GDOT Engineering Districts under Case 2 and Case 4 scenarios are shown in Figure 3 and 4. As shown in Figure 3, the largest composite rating difference among the 7 Districts is about 7, while it is less than 1 in Case 4 (Figure 4). The system is very effective in balancing pavement performance among different districts.

Case 5: Raise the yearly composite rating requirement from 85 to around 90. The average yearly funding needed increases from $65.27 to $227.36 million dollars.

The results indicate that different funding distributions could result in different pavement performance consequences. It is worth mentioning that a one-point composite rating increase in one year is quite significant, as it represents the increase of pavement performance rating by 1 point for the entire 36,348-lane mile in the statewide pavement network. Based on the pavement performance/deterioration model for the pavements in the Georgia, if no MR&R activities apply, the performance rating of a pavement drops by 2.5 to 4.0, depending on the pavement surface types (asphalt pavement, slurry seals, etc.) and traffic volume (low, medium and high AADT). Consider the variances of pavement performance due to different funding distribution in the cases studied above, the impact of funding distribution on pavement performance is very significant.

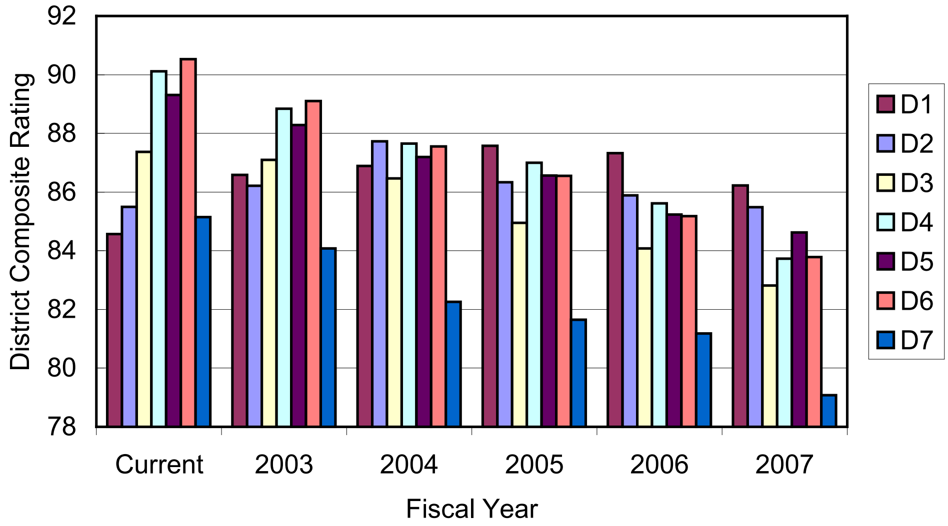



Figure 3: District-Level Pavement performance Distribution with no balance constraint

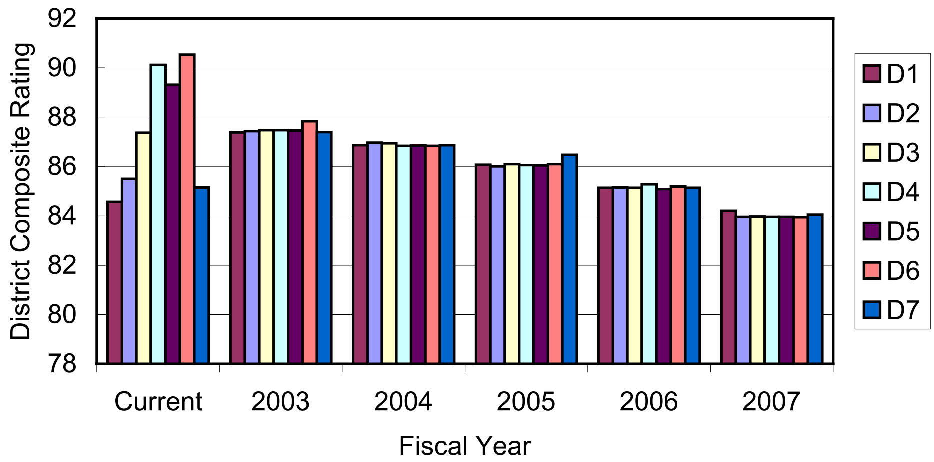



Figure 4: District-Level Pavement performance Distribution with balance constraint

## 7. CONCLUSIONS

This paper presents a multi-year pavement rehabilitation need analysis system developed for GDOT for formulating better long term pavement rehabilitation plans to achieve better overall pavement performance. The characteristics and benefits of the multi-year need analysis provided in the system are summarized below:

1. Network-level and project level analyses are combined in the multi-year need analysis. This allows the decision makers to link the network-level requirements, such as a desirable statewide composite rating, with the project level actions as when, where, and what to treat.
2. The system can perform various types of analyses, such as determining multi-year minimum budget to meet prescribed pavement performance requirements, determining optimum pavement rehabilitation plans subject to funding availability, and other requirements such as balancing funding distribution or future pavement performance among GDOT Engineering Districts or State Congressional Districts.
3. The computation time required to perform the analysis is quite fast, thus allowed the user to perform various scenarios for multi-year pavement needs analyses and compare the results.
4. The following summarize the findings of the case studies presented in this paper:
    a. In order to achieve a specified statewide composite rating of 85 every year for the upcoming 5 years, a minimum dollars can be obtained. For a higher specified composite rating, higher annual funding will be anticipated. For example, it is expected to spend 2.5 times more funding to maintain a composite rating of 90 comparing with 85.
    b. Spending the money evenly for the coming 5-anlaytical years is one way to distribute the funding, and it may not be the best way to address the needs in Georgia based on current statewide pavement condition because the composite rating in the last year may not meet the acceptable level.
    c. For a 5-year time frame, a higher average 5-year composite rating will be obtained if money is spent earlier like the preventive maintenance practices compared in Cases 1 and 3. However, a lower residual value was shown in Case 3 than Case 1 based on a fixed amount of available funding.
    d. The statewide composite rating will be decreased by considering an additional policy constraint, balancing the funding in 7 GDOT engineering districts, in this case. In other words, it requires more money to maintain the system to a specified performance level for a 5-year time frame. Further study (e.g. a 10 or 20-year analysis) can be conducted to see if the policy impact will come to a steady state of spending the same amount of funding.
5. The examples presented in this paper were based on the year 2002 actual statewide pavement condition evaluation data for asphalt pavements. However, some asphalt pavements with higher ratings and in the Interstate highways were not surveyed in year 2002. Therefore, the results presented in the examples do not reflect the actual statewide asphalt pavement rehabilitation needs. This does not, however, diminish the value of the system.
6. The following are some improvements currently under development for the system:
    - Need analysis for concrete pavement is under development.
    - The pavement needs analysis conducted in this paper focuses on only pavement physical condition, which is the core of the pavement management. However, the analysis could be extended in the future to incorporate traffic volume, functional need, and user cost.

- The present system uses a deterministic pavement performance/deterioration model. Incorporating probabilistic pavement performance/deterioration model in the system is under development.
- Incorporating various GIS functions into the system are under development to allows the users to display pavement conditions and rehabilitation plans on GIS map and to make changes of the rehabilitation plans directly on the GIS maps and the changes will be reflected automatically in the database.

## 8. ACKNOWLEDGEMENT

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