Needs Based Assessment of Pavements Using Multi-Constraint Optimization

VDOT, Maintenance Division

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Background – Optimization

- Optimization is a mathematical process of choosing the best possible solution from a set of feasible alternatives
- For pavement network it involves choosing the set of treatments that typically either maximizes the benefits or minimizes the cost
- One or more constraints are applied

Background – Optimization Analysis

- Allows user to specify desired condition or specify budget
- Allows multiple scenario analyses
- Develop cost-effective work plans
- Identify treatment at individual section level
- Assists in budget allocation
- Multi-constraint analysis
- Multi-year analysis

Background – PMS Project Implementation

- New PMS implemented in May 2010
  - Stores, retrieves and processes VDOT condition and inventory data
- Primary features of the new software:
  - Analysis of current pavement conditions
  - Pavement performance modeling and forecasting
  - Calculation of performance based needs expectations
- Two Phase Implementation

PMS Project Implementation – Phase 1

- Initial data loading
- Fast system configuration
- Quick implementation of analysis tools
  - Utilized newly developed optimization system
  - VDOT needed to complete yearly analysis
- VDOT condition survey was basis for linear network
- Phase 1 Completed – November 2008
- Used for Multi-Constraint optimization in 2008 and 2009
  - Needs determination
  - Treatment recommendations

PMS Project – Phase 2

- Revise all data input to obtain location referencing from VDOT RNS system
- Implement strategy based multi-year optimization tool
- Finalize major linear referencing interfaces
- System and user acceptance testing
- Go live – May 2010

Network Analysis – Requirements

- VDOT Requirements
  - Produce a work plan recommending treatment on section level
  - Utilize existing VDOT decision processes
  - Allow for use of multiple constraints
  - Reduce need for multiple scenarios to account for different constraint levels
  - Utilize optimization techniques

Network Analysis – Goals for the Tool

Goal: Find best set of projects to meet objective within multiple constraints

Input

- **Objective**
  - **Maximize benefit, minimize treatment cost, maximize condition threshold**
- **Constraints**
  - **Maintain certain average conditions**
  - **Meet maximum allowable deficiency targets**
  - **Achieve desired mix of treatments**
  - **Remain below required budget**

Output

- **Work Plan**
  - **Which sections to fix (WHERE)**
  - **Using which treatments (WHAT)**
  - **In which year (WHEN)**
- **Work plan generates all needed analysis summaries**
  - **expected condition, cost, benefit etc.**

Maintenance Activity Categories

- Do Nothing (DN)
- Preventive Maintenance (PM)
  - Crack sealing, slurry seal
- Corrective Maintenance (CM)
  - Partial depth patching and <=2” overlay
- Restorative Maintenance (RM)
  - Full depth patching and <=4” overlay
- Major Rehabilitation/Reconstruction (RC)
  - Break and seat, reconstruction

Network Analysis – Multi-Constraint

- **Multi-Constraint Analysis**
  - **Integer programming optimization approach**
    - All sections either "treated" (1) or "not treated" (0) in a given year
  - **Existing VDOT decision process determines possible treatments per section**
    - Limits possible treatment selections
  - **Integer solver choose best set of project for a given year**
  - **Results from one year as input for next year's analysis**

Network Analysis – Multi-Year, Multi-Constraint

- **Multi-Year, Multi-Constraint Analysis**
  - **Expand multi-constraint analysis to look at treatment strategies for each section**
    - Strategy: A series of treatments prescribed for a given section across all years in the analysis scope
    - VDOT decision trees still used for possible treatment selection
  - **Solver selects best set of strategies for entire analysis period**
    - Still an integer programming optimization approach
    - A particular strategy is either applied to a specific section (1) or it is not (0)
    - Each section MUST receive a strategy, so strategy definitions are important (e.g. don't forget the "Do Nothing" strategy!)

Network Analysis – Methods

- **Analysis Options**
  - **Available Objectives**
    - Maximize benefit (“area under the curve”)
    - Maximize condition indicator (wtd. avg., % above threshold, total)
    - Minimize total cost
  - **Available Constraints**
    - Treatment costs (with % yearly budget variability in multi-year)
    - Desired condition level (average, % above threshold, total)

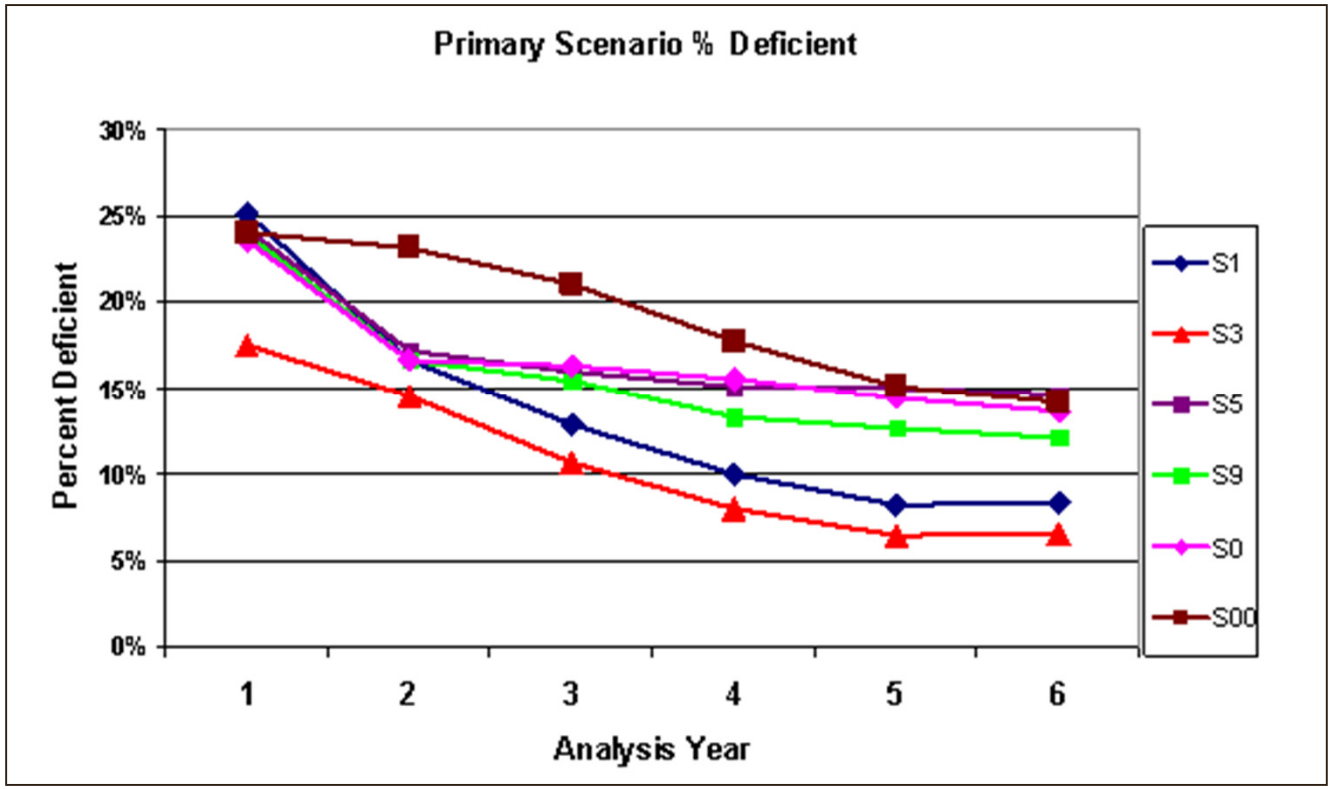
Network Analysis – VDOT Use

- Analysis conducted on VDOT interstate and primary pavements
- Interstate network – approximately 5,000 lane miles
- Primary network – approximately 21,000 lane miles
- Condition data collected from annual surveys used for analysis

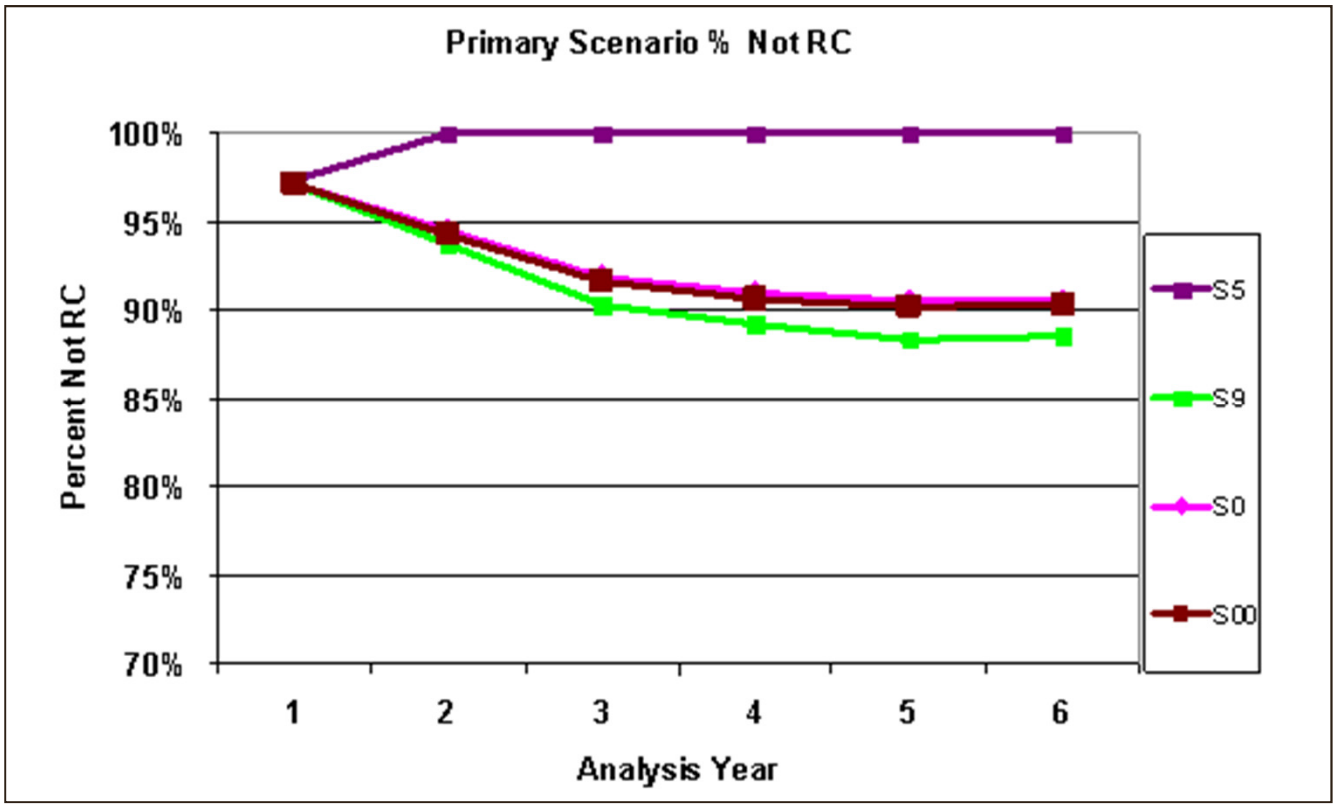
Network Analysis – Description of Scenarios

- **For the purpose of the investigation, 6 optimizations were run:**
  - **S1: Single constraint, 6 year analysis, IS and PR**
    - Objective: Maximize benefit
    - Constraint: Budget constraints causing % deficient <18% by Y2
  - **S3: Single constraint, 6 year analysis, IS and PR**
    - Objective: Maximize benefit
    - Constraint: Budget constraints causing % deficient <18% by Y1
  - **S5: Multiple constraints, 6 year analysis, IS and PR**
    - Objective: Minimize treatment cost
    - Constraint: % deficient < 18% / % not needing RC = 100% by Y2
  - **S9: Multiple constraints, 6 year analysis, IS and PR**
    - Objective: Minimize treatment cost
    - Constraint: % deficient < 18% by Y2 / maintain current CCI
  - **S0: Multiple constraints, 6 year analysis, IS and PR**
    - Objective: Minimize treatment cost
    - Constraint: % deficient < 18% / % not needing RC = 90% by Y2 / maintain current CCI
  - **S00: Multiple constraints, 6 year analysis, PR only**
    - Objective: Minimize treatment cost
    - Constraint: % deficient < 18% / % not needing RC = 90% by Y4 / maintain current CCI

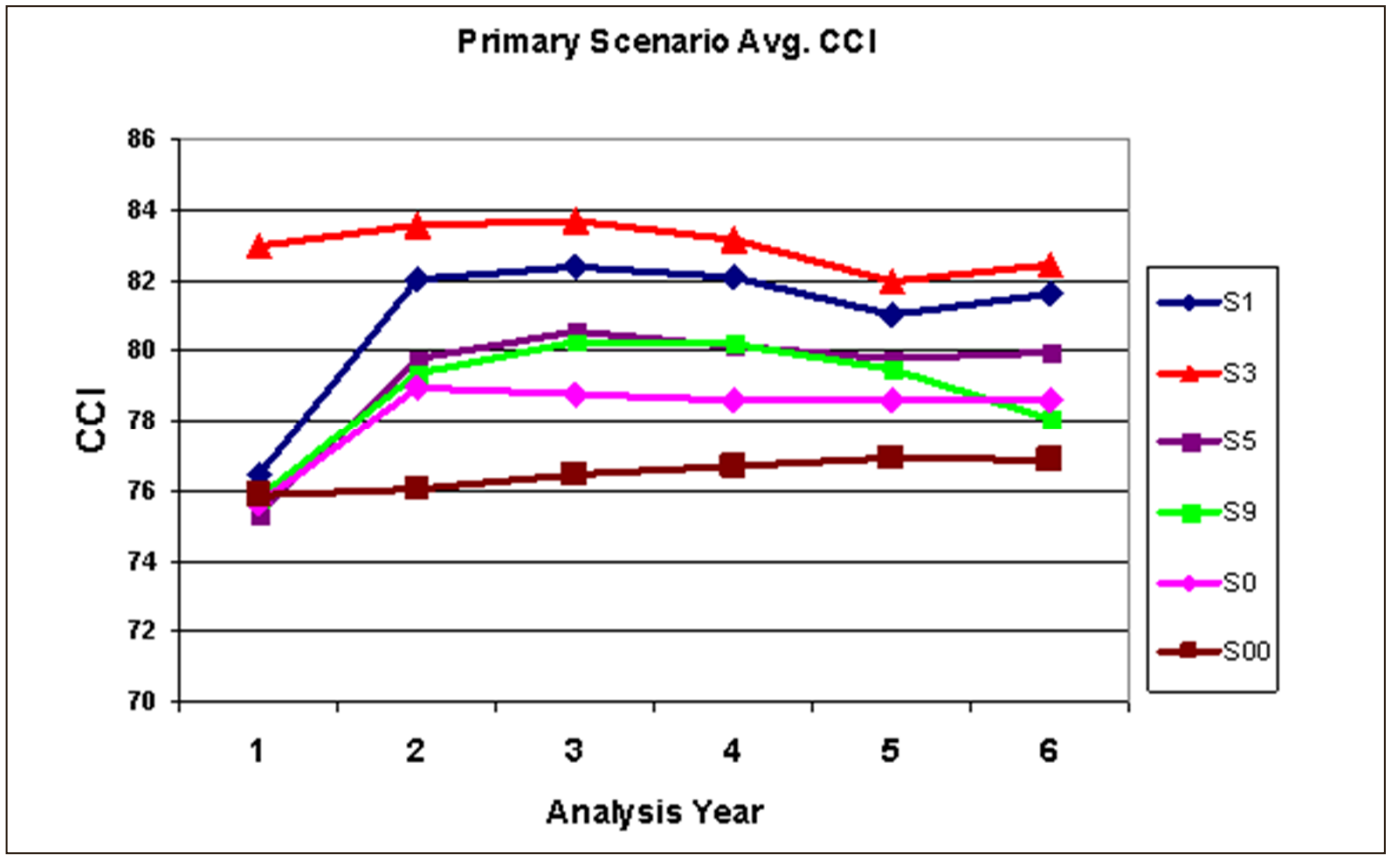
Network Analysis – Primary % Deficient



Network Analysis – Primary % Not Needing RC



Network Analysis – Primary Average CCI



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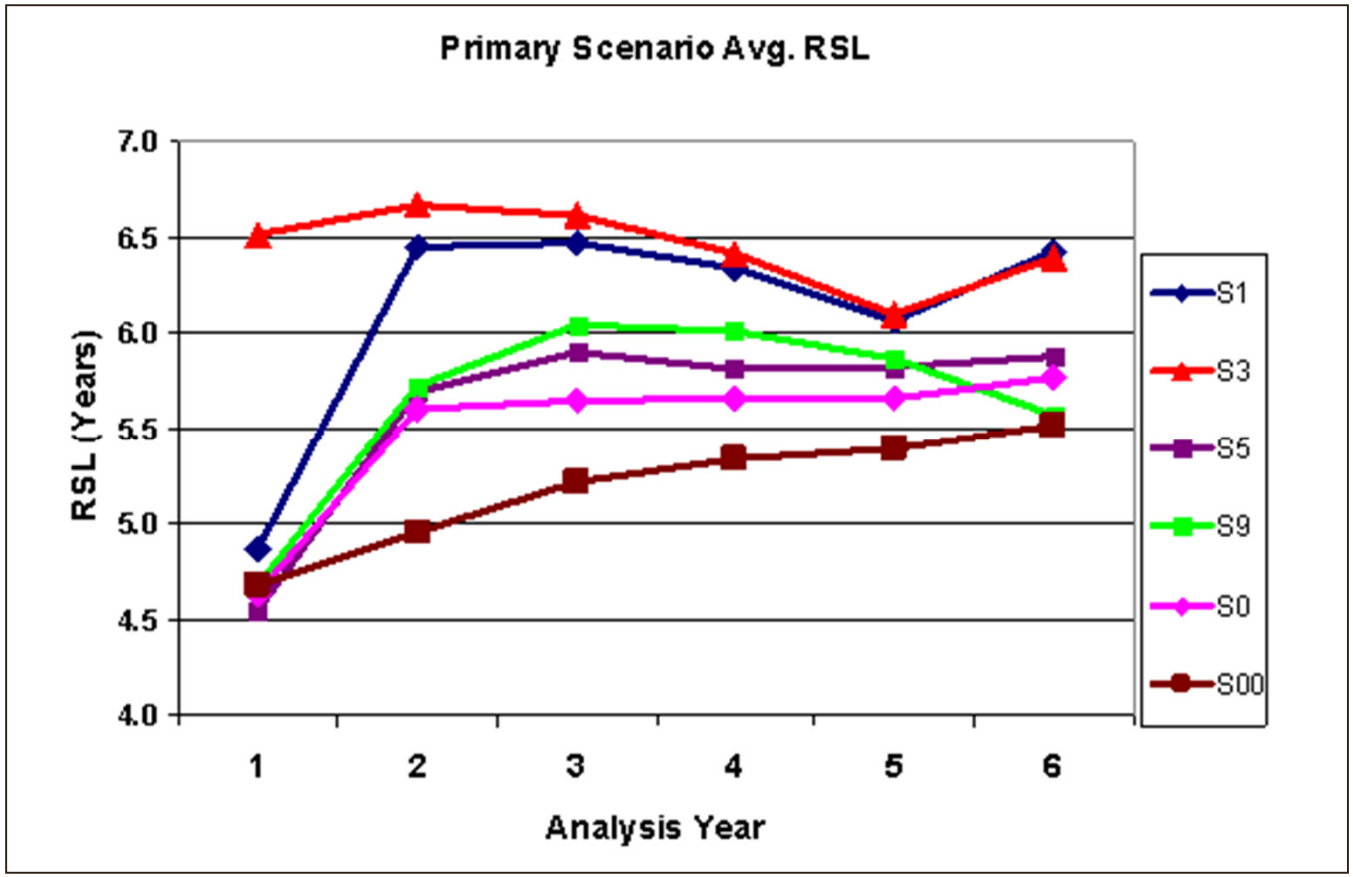

Summary

- Either single or multiple constraints can be used
- The following outputs of the analysis are determined in various years:
  - Percent deficient pavements
  - Percent of network not requiring major rehabilitation or reconstruction
  - Average CCI of the network
  - Average RSL

Lessons Learned

- **Realistic Constraints**
  - **Individually and in Combination**
  - **Targets reflect network condition**
  - **Avoid infeasible solutions**

- **Monitor the Results**
  - **Implementable**
    - VDOT and Industry Perspective
  - **“Best Mix of Fixes”**

Thank you