Development of network-level linear programming optimization for pavement maintenance programming

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The research presented in this paper builds upon prior research (de la Garza and Krueger, 2007). In their research, highway maintenance managers, through what-if analysis, allocate the available budget manually and then observe how this new budget allocation strategy influences the overall network performance. Thus, there was an opportunity to improve on this research by developing a model which is capable of performing such budget allocation processes optimally. In this research a decision-making tool is developed which is capable of performing network-level optimization for the pavement maintenance programming problem through the application of the Linear Programming (LP) methodology. Previously proposed optimization approaches have, in particular, two essential elements, namely optimization algorithms and pavement performance prediction models. Such elements could vary remarkably depending on the researchers’ approach to the problem (Li et al. 1997, Rohde et al. 1997, Abaza and Ashur 1999, Chen et al. 1996, Liu and Wang 1996, Mbwana and Turnquist 1996, Ravirala et al. 1997, Tack and Chou 2002, Cheu et al. 2004).

This LP optimization model’s variables, parameters, constraints and objective function are defined as follows:

- \( P \): a Set of Funding Periods (1, 2, 3, 4, ………, i, ………., 15)
- \( S \): a Set of Pavement Condition States (Very Poor, Poor, Fair, Good, Excellent)
- \( R \): a Set of Treatments (Reconstruction, Rehabilitation1, Rehabilitation2, Thick Overlay2, Thick Overlay3, Thin Overlay3, Thin Overlay4, Ordinary Maintenance3, Ordinary Maintenance4)
- \( B_i \): Highway Maintenance Budget available within period \( i \), \( \forall i \in P \)
- \( U_{ij} \): Unit (Per lane-mile) cost of treatment \( j \) within period \( i \), \( \forall i \in P \) and \( \forall j \in R \)
- \( N_{ki0} \): Number of lane-miles in condition \( k \) at the beginning of year 1 (Baseline condition), \( \forall i \in P \) and \( \forall k \in S \)
- \( G_{ki} \): Number of lane-miles in condition \( k \) at the end of period \( i \) (Target specified by VDOT), \( \forall i \in P \) and \( \forall k \in S \)
- \( D_{(k+1)k} \): Deterioration Rate from condition state \( (k+1) \) to condition state \( k \), \( \forall k \in S \)
- \( X_{ij} \): Amount of money spent on treatment \( j \) within period \( i \), \( \forall i \in P \) and \( \forall j \in R \)
- \( N_{ki} \): Number of lane-miles in condition \( k \) at the end of period \( i \), \( \forall i \in P \) and \( \forall k \in S \)

The objective function stated below is a generic objective function. The terms \( w_i, w_2, w_3, w_4 \) and \( w_5 \) represent possible weighting coefficients pertaining to each condition state.

\[
\text{Minimize} \quad \sum_{i \in P} \left( (w_1 * N_{i1}) \pm (w_2 * N_{2i}) \pm (w_3 * N_{3i}) \pm (w_4 * N_{4i}) \pm (w_5 * N_{5i}) \right)
\] (1)
The problem statement given next is included to demonstrate the model. Additional optimization scenarios may be found in (Akylidiz, 2008). “How should VDOT allocate its annual highway maintenance budget for different renewal activities such that the number of lane-miles in very poor, poor, and fair condition will be minimized while excess budget will be used towards maximizing the number of lane-miles in excellent condition?”

\[
\text{Minimize } \sum_{i \in P} \left( (N_{1i} + N_{2i} + N_{3i}) - (N_{4i} + 5 \times N_{5i}) \right)
\]  

(2)

Table 1. Number of lane-miles in each condition state

| Condition State          | Baseline | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6 | Year 7 | Year 8 | Year 9 | Year 10 | Year 11 | Year 12 | Year 13 | Year 14 | Year 15 |
|--------------------------|----------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Target Very Poor Condition | 25.0     | 43.7   | 58.0   | 25.0   | 25.0   | 0.0    | 12.5   | 25.0   | 24.0   | 8.6    | 0.0    | 0.0    | 0.0    | 0.0    | 0.0    |
| Target Poor Condition    | 75.0     | 106.3  | 47.4   | 50.0   | 50.0   | 50.0   | 50.0   | 23.0   | 0.0    | 0.0    | 0.0    | 0.0    | 0.0    | 0.0    | 0.0    |
| Target Fair Condition    | 150.0    | 186.5  | 64.3   | 76.6   | 37.5   | 37.5   | 22.8   | 0.0    | 0.0    | 0.0    | 0.0    | 0.0    | 0.0    | 0.0    | 0.0    |
| Target Excellent Condition | 175.0   | 165.0  | 438.3  | 123.1  | 268.6  | 144.2  | 0.0    | 0.0    | 0.0    | 0.0    | 0.0    | 0.0    | 0.0    | 0.0    | 0.0    |

Findings indicate that prior results obtained based on manual budget allocation are inferior to what is presented in this paper. The network-level optimization problem developed herein searched for the optimal pavement maintenance program considering 15 years of analysis, whereas in a manual budget allocation process, the decision-maker arbitrarily allocates money into renewal activities in the first year, and then reiterates the same process for the following 14 years.

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References


