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Trade-off analysis for infrastructure management: new approaches to cross-asset challenges

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Abstract

As transportation infrastructure managers pursue performance-based management, increased scrutiny is rightfully imposed by the stakeholders (tax-payers and their legislative representatives).
The performance of public transportation agencies is not evaluated on a single asset type (i.e. on Pavement, or Bridges alone) but on the system as a whole (cross-assets). Many commercial software packages are focused on managing a single asset type making cross-asset analysis difficult. However, a main problem for transportation agency managers is how to split available budget among different types of assets to provide the best overall performance to the public stakeholders.
This paper focuses on two different approaches to the Cross-Asset Problem (CAP) and demonstrates, using real data examples, how optimal budget distribution for various asset types can be found for large agencies.
The paper formulates individual asset management as an integer optimization problem (IP).
It then discusses two approaches to the CAP. The first approach assumes that overall agency performance can be expressed as a linear combination of individual asset type performances. In this case the CAP can be formulated as an Integer Optimization Problem (IP) where its objective and constraints are defined as a simple linear combination of the objectives/constraints for corresponding asset types. Model formulation, running times and optimal budget distributions using real transportation agency data are presented for this approach.
The second approach requires no assumptions on the CAPs objective formula and considers separate asset type problems as a black box which, for a given budget distribution, returns the best overall performance for that asset type. A Derivative Free Optimization algorithm is presented for this setup, showing running time and final budget distributions for several examples.

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Finally, the paper outlines the advantages and disadvantages of each approach and provides guidance on when each approach should be used.

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Keywords: Asset management; trade-off; analysis; infrastructure management; cross-asset; integer optimization

1. Introduction

Public transportation agency performance is not evaluated on a single asset type like Pavements or Bridges alone, but on the network as a whole (cross-assets), hence, multi-asset management tools are needed to manage the infrastructure.

Many commercial software packages are focused on managing a single asset type and provide a way to do a what-if analysis for that one asset type. There is no easy way to combine several such packages into an efficient cross-asset planning tool, which makes trade-off analysis difficult. An investigation performed by Caltrans Division of Research and Innovation (DRI) showed that currently only two agencies perform cross-asset management - North Carolina DOT and Utah DOT. AgileAssets is among the first to provide a comprehensive and powerful cross-asset Maintenance and Repair (M&R) planning tool to transportation agency managers that allows them to manage the strategic portfolio while providing detailed plans for specific goals. This is the solution used by North Carolina DOT.

This paper presents two approaches for the Cross-Asset Problem (CAP) and demonstrates, using real data examples, how desirable system performance can be achieved by grouping and scheduling projects across two asset types (pavements and bridges for this example). One of the key decisions made on the transportation network by executives is how to split available funds between different asset types to maximize overall infrastructure performance. For example, North Carolina DOT is responsible for maintaining both bridges and pavements. What amount should they spend on bridges and what amount on pavements? More importantly, what would be the impact of different budget distributions on overall performance? This is a typical trade-off analysis problem that can be solved using CAP.

We formulate management of individual assets as an integer optimization problem (IP). The paper discusses two approaches to the CAP. The first approach assumes that transportation network performance can be expressed as a linear combination of individual asset performances. In this case the CAP can be formulated as an Integer Optimization Problem (IP) with objective and constraints defined as a simple linear combination of the objective and constraints for the specific asset types. Model formulation, running times and optimal budget distributions using real transportation agency data for this approach are presented below.

The second approach does not have any assumptions on the CAP's objective formulation and considers separate asset type problems as a black box, which for a given budget distribution returns the best overall performance for that asset type. A Derivative Free Optimization algorithm for this setup and its running time and final budget distributions for different instances are presented.

2. Cross asset problem Structure

The Cross Asset Model can be used to combine single asset optimization models for different asset types. In order to solve the CAP efficiently the single asset optimization models used should be computationally attractive. The authors found that a strategy based Integer Programming formulation is a good candidate for use as a single asset model. There are several reasons in favor of that choice. First, special heuristics and solver adjustments can be used to reduce running times, making it possible to solve large networks. Second, this formulation allows for flexible asset performance models and variable model size. For details see Scheinberg and Anastasopoulos [2010], Bhargava et al. [2013].

The following is a brief description of generalized asset management model formulation that utilizes strategies: