Transportation Research Part D 32 (2014) 435–445

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

A multi criteria decision analysis technique for including environmental impacts in sustainable infrastructure management business practices

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ARTICLE INFO

Keywords:
Sustainability
Decision analysis
Pavement management
Energy consumption
Sustainable infrastructure management

ABSTRACT

This paper presents a decision analysis technique to allow highway agencies to assess the tradeoffs between costs, condition and energy consumption. It is shown how the entire feasible solution space can be evaluated between multiple stakeholders with differing values to assess the desirability of the outcomes resulting from infrastructure management decisions. Furthermore, an example network-level analysis is presented using data from the Virginia Department of Transportation. The example analysis clearly shows a tradeoff between the most cost effective outcomes (i.e., minimizing the cost divided by the condition) and the outcomes where the energy consumption is minimized, and how decision analysis should account for this tradeoff. The results of the method presented in this paper show that various pavement management alternatives can be represented in terms of desirability, and that this desirability can assist the decision maker with making decisions about performance goals and targets.

Introduction

A key aspect of sustainable development is understanding the tradeoffs that exist between maintaining quality and cost effective infrastructure while also mitigating adverse impacts on social and environmental systems (ASCE, 2012). However, many long term environmental and social impacts related to infrastructure still contain a relatively high level of uncertainty. As a framework to build policy decisions around high levels of uncertainty pertaining to environmental and social impacts, many countries have adopted versions of the precautionary principle (Gollier et al., 2000; Kriebel et al., 2001). The precautionary principle employs an anticipatory attitude towards irreversible and potentially harmful environmental and social impacts, such as the current rate of unsustainable consumption of non-renewable energy. The precautionary principle states that a lack of full scientific certainty should not preclude actions towards mitigating potential harms caused by actions resulting in such impacts. A major component of the precautionary principle is the idea that scientific uncertainties are

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http://dx.doi.org/10.1016/j.trd.2014.08.019
1361-9209/

resolved over time, and that policy makers should adapt their method of decision making such that they continually learn about and update the potential solution space regarding their specific objectives.

It has been proposed that a key component of the precautionary principle, an evaluation of an entire feasible solution space including all potential outcomes, can be applied to enhance sustainable development in the face of long-term uncertainties about adverse impacts (Steele, 2006). Inherent in this approach is the idea that sustainable development must be evaluated as a multi criteria problem, and that policy makers should be presented with a solution space of many feasible outcomes, as opposed to a single optimal solution. Many researchers have proposed multi criteria decision analysis approaches with the goal of seeking an optimum, or most desirable solution given the tradeoffs in various infrastructure management criteria (Li and Sinha, 2004; Zietsman et al., 2006; Smith and Tighe, 2006; Stich et al., 2011). However, a method to present the entire solution space in terms of the optimality or desirability of various outcomes in relation to commonly used variables in infrastructure management (e.g., cost or infrastructure condition) has yet to be developed. In light of this, a method to evaluate and represent a multi criteria decision problem over an entire feasible solution space is presented in this paper. The analysis is presented in terms of pavement management and energy consumption, but it is expected that the techniques presented will be applicable to many fields.

Objective

The objective of this paper is to present a practical multi-criteria decision making technique for pavement management applications. The technique focuses on representing the desirability or optimality of a set of potential outcomes in terms of commonly used variables in pavement management (i.e., cost of maintenance and condition of the pavement). The variable used in this analysis to represent adverse environmental impacts is energy consumption. The anticipated benefit of the methodology presented in this paper is that it will result in an adaptive decision-analysis tool that policy makers can use to learn about feasible outcomes and the resulting impact of weights they place on certain variables (e.g., costs, energy consumption, etc.). It is also expected that the decision method presented in this paper will assist agencies in working with the public when setting policy decisions regarding tradeoffs to adverse environmental impacts, as recommended to the National Academies of Sciences (Dietz and Stern, 2008).

Background

Sustainable pavement management is an emerging area of research that is concerned with maintaining acceptable condition of pavements while also considering the tradeoffs between cost, environmental impacts and social impacts of pavement investments. Generally the tradeoffs between economic, environmental and social factors require that the agency in charge of managing pavements maintains an accurate database that includes the pavement condition and models to predict the resulting impacts of pavement management decisions on each of the factors. Most efforts to date have focused on defining pavement sustainability and sustainable performance measures. However, a next critical step is implementing sustainability into the pavement management decision-making process. This includes incorporating sustainability as a fundamental business practice within the agency where considerations about project selection, treatment type selection, lifecycle management, and triple bottom line (economic, environmental and social) tradeoffs are addressed in the initial decision processes.

The multi-objective decision problem arising from sustainable pavement management is generally converted to a single objective problem by treating some of the objectives as the constraints (Wu and Flintsch, 2009). In this way, an agency seeks to maximize or minimize one particular objective (e.g., minimizing the cost divided by the performance of the pavement condition) subject to constraints that arise from the original objectives. A shortcoming with the single criterion approach is that when objectives are reformulated as constraints, the resulting analysis becomes non-compensatory (Goodwin and Wright, 1998). In other words, undesirable values in the newly formulated constraints are no longer compensated for by highly desirable values in the objective values. Consequently, there is no longer a guarantee that the selected value is non-dominated, and a more optimal value may exist depending on the extent to which the constraints are relaxed. Secondly, the non-compensatory analysis tends to bias the results to the parameter that is chosen as the objective function, thus rendering other objectives as lower level considerations.

Many methods have been proposed for finding solutions to the multi-objective problems encountered in the transportation setting, such as utility theory (Li and Sinha, 2004; Zietsman et al., 2006), the analytical hierarchy process (Smith and Tighe, 2006) as well as rank aggregation methods when limited alternatives are presented (Stich et al., 2011). Each method has demonstrated advantages and shortcomings, and thus no widely accepted method has been adopted by the transportation sector. This paper will demonstrate a method for finding many feasible solutions to the multi-criteria problem posed by sustainable pavement management by combining the benefits cited for other proposed methods into the development of a novel new technique. Instead of developing a single *'optimal'* solution, this paper will demonstrate the benefits of analyzing the feasible set of optimal solutions as a function of the value functions and weights applied to each parameter. The expected benefit of this approach is that the solutions also act as a communication tool between many stakeholders, allowing for tradeoffs required between many the variables to be made clear.