Comparative Simulation Analysis of Pavement Technology for a Decision Support System in the U.S. Road Renewal Industry

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Abstract

In the United States, State Departments of Transportation (DOTs) and other public sector owners of highway infrastructure have been facing poor road conditions, significant funding shortfalls, and increasing traffic congestion over the past decade. In response to the challenge, the U.S. road renewal industry is developing partnerships to explore ways to improve roadway performance while taking into consideration the overall lifecycle costs of rehabilitating countless miles of existing roads. To identify those pavement strategies that will likely have the most cost-effective and highest performance in the U.S. industry, the researchers developed a technology analysis framework that consisted of two analyses: economic and non-economic analyses. Furthermore, four pavement strategies that industry experts believe will dominate the U.S. road renewal industry during the next ten years were analyzed, including: Dense-Grade Hot Mix Asphalt (HMA), Stone Matrix Asphalt (SMA), Open Graded Friction Course (OGFC), and Warm Mix Asphalt (WMA). In the study, our analysis demonstrated the extent to which the four pavement strategies impact the quality and costs associated with highway construction and maintenance during the life of each pavement strategy. The analyses resulted in rank-ordering the pavements based on their economic and non-economic performance. The research ultimately combined the economic and non-economic benefits to achieve an overall rank-ordering of efficient pavement strategies as follows: (a) Stone Matrix Asphalt (SMA), (b) Dense-Grade Hot Mix Asphalt (HMA), (c) Warm Mix Asphalt (WMA), and (d) Open-Graded Friction Course (OGFC).

Keywords: road renewal, pavement, life cycle cost, comparative assessment, DOTs

1. Introduction

Public projects tend to have a reputation for being slow, costly, and anachronistic (Hwang et al., 2011). Especially over the past decade, the transportation industry has been struggling with the issues of high user demand, and increasing budget pressure (ASCE, 2009; Anastasopoulos et al., 2010; Brach and Wachs, 2005; FHWA, 1999). In fact, annually $50 billion is invested to upgrade and maintain the deteriorated highway system (Garza et al., 2011; Lemer, 2004). In 1988, the National Council on Public Works Improvement published their first report on the condition of the nation’s fragile infrastructure, including its highway system. The report highlighted significant shortfalls in infrastructure capital investment and a corresponding performance deterioration that had occurred over a 25-year period. The overall grade assigned to the entire system was a ‘C’, indicating that the public works system was barely adequate to support the demand (NCPWI, 1988). Furthermore, the highway system received a ‘C+’ in 1988, with weaknesses identified in road expansions, bridges, and rural roads. Recently, the nation’s roadways were assigned a grade of ‘D’ by the American Society of Civil Engineers, with significant funding shortfalls, poor road conditions, and increasing congestion contributing to current state of the highway and road systems (ASCE, 2005). Experts estimate that $94 billion is needed each year to improve the highway system; however, only $54 billion is typically allocated, resulting in a funding shortfall of $40 billion each year (ASCE, 2005). Consequently, experts believe the highway system will continue to decline unless significant improvements can be made in the quality of the pavements and until longer-lasting roads can be produced.

Therefore, there is a need to improve quality and increase the service life of pavements while reducing maintenance and rehabilitation costs. A recent study demonstrated the impact of quality on the life cycle costs of a project (Zhang and Damnjanovic, 2006). In the study, several levels of quality were compared for...
both asphalt and concrete pavements, and, in all comparisons, the higher quality product had: (a) lower maintenance and repair costs, (b) longer durations in service before rehabilitation was necessary, and (c) a longer overall life. The higher quality products tended to have higher initial (construction) costs, but these higher initial costs were offset by the savings achieved through lower maintenance, repair, and rehabilitation costs. Consequently, higher quality of the end-product can result in a decrease in overall life cycle costs within the road renewal industry. In order to achieve this goal, there is an immediate need for identifying cost-effective and high performance pavement strategies by quantifying total life cycle costs as well as potential performance of the pavement strategies.

2. Framework for Envisioning Road Renewal Improvement

2.1 Overview of the Framework

Recently, Caterpillar Inc. teamed up with the University of Texas at Austin to identify pavement strategies that will be used more extensively in the next decade to renew millions of miles of U.S. roadways. A key objective of the research was to identify those high-performance, cost-effective pavement strategies in the U.S. road renewal industry that will likely be in greatest demand by industry professionals. To achieve this goal, the following objectives were identified:
1. To evaluate and prioritize pavement strategies based on life cycle cost analysis
2. To develop a quantitative economic indicator of efficient pavement strategies
3. To address the non-economic impacts of each pavement strategy

One unique way to evaluate the performance of a pavement strategy is to combine Life Cycle Cost Analysis (LCCA) with a non-economic analysis. LCCA is a technique for identifying the lowest cost alternative that meets a project’s performance objectives. A non-economic analysis is a technique based on expert opinions to assess pavement performance in terms of four attributes, namely long lasting, energy saving, noise-reducing, and skid-resistant properties. To identify those pavement strategies that will likely have the most significant impact on industry efficiency, the Technology Analysis Framework described in Fig. 1 was used by quantifying total life cycle costs as well as potential performance of the pavement strategies, which ultimately impact road renewal efficiency in the transportation industry.

2.2 Life Cycle Cost Analysis (LCCA) Primer

Life cycle cost analysis is one of the most commonly used engineering economic tools that can be employed to determine the lowest cost alternative among several alternatives to meet project’s objectives. The Federal Highway Administration (FHWA) recently adopted LCCA as part of a comprehensive asset management program that involves asset management, system preservation, pavement management and analysis, bridge management and inspection, and construction and maintenance activities (FHWA, 2007). Two types of costs are considered in the LCCA method: agency costs and user costs. To compare the relative efficiency among alternative pavement strategies, two economic indicators are also used: Net Present Value (NPV) and Equivalent Uniform Annual Costs (EUAC).

2.2.1 Agency Costs

Agency costs are all costs incurred by construction and maintenance activities over the life of the project. These costs usually include costs of construction, construction traffic control, construction mobilization, and all future maintenance and rehabilitation.

2.2.2 User Costs

User costs are the delay, vehicle operating, and crash costs incurred by the users of a facility. These costs consist of: (a) delay costs associated with the construction work zone, (b) vehicle operating costs resulting from deterioration of the pavement and work zone costs, and (c) crash costs. Therefore, user costs are highly influenced by road capacity. As a result, more vehicles will be impacted by a construction work zone 20 years from now than will be impacted 10 years from now because the volume in 20 years will be significantly higher than the volume in 10 years. Previous studies have been performed to establish reasonable user delay costs. The FHWA recommended user delay costs are provided in Table 1.

In addition, the capacity of roads is influenced by number of closed lanes, and length of closure during construction or maintenance activities. Therefore, user costs typically include increased Vehicle Operating Costs (VOC), delay costs, and crash costs to highway users due to traffic congestion caused by work zones. User costs are strongly influenced by roadway characteristics and the growth rate of traffic. User delay costs tend to increase with time because the volume of traffic also increases with time.

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>$ Value per Vehicle Hour (in 2006 US dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger Vehicle</td>
<td>$15.56 to $17.47</td>
</tr>
<tr>
<td>Single-Unit Trucks</td>
<td>$24.92 to $26.88</td>
</tr>
<tr>
<td>Combination Trucks</td>
<td>$29.98 to $32.25</td>
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2.2.3 Comparative Simulation Analysis

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