DECISION SUPPORT SYSTEM OF PAVEMENT SELECTION IN EMERGING ECONOMIES

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Choosing rigid or flexible pavement is an important decision in infrastructure development projects and can improve public investment efficiency. Various studies have been conducted over the past few decades to compare between rigid and flexible pavement. Studies indicate that rigid pavement can have longer service life and require less maintenance costs, while others indicate that flexible pavement can have lower initial investment costs. Previous discussion tended to favor rigid pavement through the lens of its life cycle cost. Regardless, no consensus is established since life cycle costs can greatly vary from different project site conditions (e.g., soil conditions), discount rate, and requirements (i.e., costs and frequency) of maintenance and repair of different transportation agencies. Few studies discuss the practical decision-making processes to choose between the pavement types. This study developed a web-based decision support system to design alternative pavements and compare their life-cycle costs under various project conditions and requirements. The system’s functions are demonstrated using two example calculations based on Vietnamese design standards, and subsequent validation has demonstrated its capability in supporting decision-making in roadway pavement. This paper contributes to the body of knowledge by demonstrating a possible decision support system to improve public investment efficiency in selecting appropriate rigid or flexible pavement design.

Keywords: Rigid pavement, Flexible pavement, Pavement design, Life-cycle cost.

1 INTRODUCTION

Transportation infrastructure is essential for economic growth and social development in countries worldwide. Among the many components of roads, pavement is one of the most critical elements that affect the road’s performance and longevity. Pavement design is a complex process that involves selecting appropriate materials, thickness, and construction methods to ensure the pavement can withstand environmental conditions and traffic loads. The two most commonly used types of pavement structures are rigid and flexible pavements, which have significant impacts on the project’s cost, performance, and useful life. While several studies have compared the costs and benefits of both pavement types, no established consensus on which pavement type is more suitable for specific projects exists (Chau et al. 2022).

In emerging economies such as Vietnam, Brazil, Russia, India, and China, resources may be limited, and it is particularly important to make wise infrastructure investment decisions (Nguyen and Dapice 2009). These countries may face challenges such as limited budgets, inadequate
infrastructure, and a need to improve public services, making it essential to prioritize investments that can have the most significant impact on long-term economic growth and development. By selecting the appropriate pavement type, transportation engineers and project managers can improve public investment efficiency in infrastructure development projects.

This paper aims to enhance the efficiency of public investment in pavement selection by presenting a web-based decision support system (DSS) that helps in designing and evaluating various pavement alternatives under different project conditions and requirements. The application is accessible via the URL link: http://GoPavement.com/, assists transportation engineers and project managers in making informed decisions regarding pavement selection. By providing a practical decision-making tool, this paper aims to enhance public investment efficiency by contributing to the selection of the most suitable pavement type for a given project.

2 LITERATURE REVIEW

The use of life cycle cost analysis (LCCA) and life cycle assessment has been shown to provide a comprehensive evaluation of the economic, social, and environmental impacts of pavement alternatives (Santos et al. 2019, Heidari et al. 2020). However, interpreting and applying the results of these analyses can be challenging, particularly for non-expert users. To address this, a DSS is needed to provide an intuitive user interface and support decision-making processes in selecting pavement alternatives. Such a system could allow users to adjust various parameters and evaluate the impacts of different pavement alternatives while visualizing the results and comparing performance.

Several studies have explored the development of DSS for pavement design and management, including those for pavement preservation treatments and pavement structure design. For instance, Santos et al. (2019) developed a DSS that uses multiple criteria decision-making to rank the priority sequence of pavement alternatives based on economic, environmental, and social dimensions. Meanwhile, the Minnesota Department of Transportation provides two free software, MnPAVE Flexible and MnPAVE Rigid 3.0, for designing flexible and rigid pavements, respectively, and a separate Excel spreadsheet to calculate initial construction costs and perform life-cycle cost analysis (Tompkins 2018, Zammarchi and Tompkins 2021). However, integrating both design and life-cycle costs for pavement selection is still challenging.

While rigid pavement is known for its durability, strength, smooth ride quality, and low maintenance requirements, making it suitable for heavy traffic loads, flexible pavement is more adaptable to changes in soil conditions and less expensive to construct, making it popular for lower volume roads (Toronto Transportation Services 2019). However, challenges such as collaboration among stakeholders need attention in emerging economies like Vietnam where the potential of rigid pavements has been identified (Chau et al. 2022). Therefore, an effective life-cycle analysis system that can support decision-making is necessary.

3 METHODOLOGY

The aim of this study is to create an accessible, web-based Decision Support System (DSS) to streamline pavement design selection in emerging economies. To evaluate the system’s performance, two examples from the flexible pavement design standard (TCVN 2006) and the rigid pavement design standard (TCVN 2012) are employed. The system’s outputs are then compared with these examples, and the findings are discussed below. In pursuit of this objective, the GoPavement.com website has been designed and developed, encompassing three primary modules: a web server, a web application, and a database.
The web server module is built using Nginx, which handles client requests from desktop and mobile web browsers. It routes requests to the Django application, where most of the logic and computations take place. The web application then persists the results to the Postgresql database, which is used to store all the information and computation results.

The working flow of the GoPavement.com website starts with the client sending a request via HTTPS protocol. The web server receives the request and forwards it to the Django web application, where the necessary computations take place. If required, the Django web application persists data to the Postgresql database. The Django web application then sends a response, usually an HTML file, back to the web server. The web server forwards the response to the client web browser, which displays the response on the screen. It is worth noting that the GoPavement.com website is presently in its beta phase, undergoing testing and continuous refinement.

4 SYSTEM FLOWCHART

The system flowchart for the pavement selection process is provided in Figure 1 below. The process comprises seven steps that guide the user through the pavement design and selection process.

Step 1 starts with the general design, where the user selects the project location, service life of the structure, type of road (e.g., expressway, roadway type 1, roadway type 2, etc.), reliability coefficients, subgrade soil type, and modulus. The reliability coefficient is determined based on the safety and service life required for the pavement. Users select the type of pavement design, with the system routing to either Step 3a and 4a for rigid pavement or Step 3b and 4b for flexible pavement. Step 2 focuses on calculating the Accumulated Equivalent Single Axle Load during the service life of the structure. The system helps calculate the Equivalent Single Axle Load (ESAL) accumulated on the pavement structure during its service life. Users can use the simpler dashboard for calculation if they already have the Accumulated ESAL on a day. Figure 2 shows step 1 and step 2 on the system.

Steps 3a and 3b involve users selecting the design materials for each layer (e.g., surface layer, base, and subbase) of the pavement (Figure 3). For rigid pavement, Steps 4a provides...
recommended thicknesses for each layer based on bending stresses of standard loads and largest loads of the heaviest vehicles. For flexible pavement, Step 4b provides recommended thicknesses for each layer based on deflection, shear stress, and bending stress of standard loads. The thicknesses are calculated to ensure that the design stress is larger than ultimate stresses. Exemplar results can be found in the system testing section.

Step 5 involves users performing a unit cost estimation for the pavement structure based on the quantity of the roadway calculated from the length, width, and thickness of each layer. The cost is calculated based on the quantity multiplied by the unit cost. Step 6 involves designing the maintenance, minor repair, and major repair for the roadway. Users can select the frequency of the maintenance and repair and determine the percentage of maintenance, minor repair, and major repair cost based on the construction cost. Step 7 computes the life cycle costs of the project and plots a cash flow diagram to show the results. Users can determine the type of pavement to use for the project based on these results.

Figure 2. General project information selection (step 1) and calculate accumulated ESAL based on traffic survey (step 2)

Figure 3. Provide material inputs to design the rigid (step 3a) and flexible pavement (step 3b).
5 TESTING THE SYSTEM DESIGN

The system was tested using the design input of two examples provided in the TCVN (2006) and TCVN (2012) design standards. The results displayed below reveal that the system’s outputs align well with those of the examples demonstrated in the design standards. A close resemblance is observed between the recommended materials and thicknesses generated by the system and the two examples from the design standards, with only minor discrepancies. Furthermore, the outputs have been verified through manual calculations, confirming that they meet the necessary requirements. Table 1 shows the system testing results for rigid pavement design and Table 2 shows the results of the test for flexible pavement design. Figure 4 illustrates the results of Step 4a and Step 4b. In both cases, the system’s outputs are compared with the said examples and found that the system’s outputs were in good agreement with the examples.

Table 1. System testing results for rigid pavement design.

<table>
<thead>
<tr>
<th>Layers</th>
<th>GoPavement.com</th>
<th>TCVN (2012) example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>Concrete slab &amp; granite aggregate (28 cm)</td>
<td>Concrete slab &amp; gravel aggregate (26 cm)</td>
</tr>
<tr>
<td>Base</td>
<td>Graded stone (25 cm)</td>
<td>Graded stone &amp; 5% cement reinforced (20 cm)</td>
</tr>
<tr>
<td>Subbase</td>
<td>Graded stone type I (15 cm)</td>
<td>Graded stone (18 cm)</td>
</tr>
</tbody>
</table>

Table 2. System testing results for flexible pavement design.

<table>
<thead>
<tr>
<th>Layers Layer</th>
<th>GoPavement.com</th>
<th>TCVN (2006) example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Layer 1</td>
<td>Fine-graded asphalt (6 cm)</td>
<td>Fine-graded asphalt type I (6 cm)</td>
</tr>
<tr>
<td>Surface Layer 2</td>
<td>Medium-graded asphalt (8 cm)</td>
<td>Fine-graded asphalt type I (8 cm)</td>
</tr>
<tr>
<td>Base</td>
<td>Graded stone type I (14 cm)</td>
<td>Graded stone with cement reinforced (14 cm)</td>
</tr>
<tr>
<td>Subbase Layer 1</td>
<td>Natural aggregate (17 cm)</td>
<td>Graded stone type I (17 cm)</td>
</tr>
<tr>
<td>Subbase Layer 2</td>
<td>Natural aggregate (18 cm)</td>
<td>Graded stone type II (18 cm)</td>
</tr>
</tbody>
</table>

Figure 4. Rigid (step 4a) and flexible (step 4b) pavement design result.

6 LIFE CYCLE COST ANALYSIS AND FUTURE RESEARCH

This section discussed life cycle cost analysis component and future research direction of the study. Figure 5 illustrates the unit cost estimation (step 5), the design of pavement maintenance and repair costs (step 6), and the life cycle cost analysis (step 7). The figure provides an overview of the functions of the system, which will be tested in the future research with real-world construction
case studies. This study contributes to the field of knowledge by addressing the current gap in pavement design and life-cycle cost analysis. Most systems have separate design and cost analysis applications, whereas this system integrates both functionalities into a single platform.

Currently, a sensitivity analysis is being developed that will be incorporated into the system in the future. User testing is planned to be conducted with professional engineers to evaluate and improve the system design. Their feedback will be analyzed to further enhance the system’s functionality and user-friendliness. Collaboration and extension of the study to other emerging economies are also being considered, which will support the sustainability strategic plans for their infrastructure development. The expansion of the system to other countries is expected to enhance its applicability and increase the efficiency of public investment in infrastructure.

![Figure 5. Unit cost estimation (step 5), pavement maintenance and repair cost design (step 6), and life cycle cost analysis (step 7).](image)

References


