A GIS Enabled Cost Estimation Tool for Road Upgrade and Maintenance to assist Road Asset Management System

Kabindra K. SHRESTHA¹, S.M.ASCE, M.S. CSIT, Pramen P. SHRESTHA², M.ASCE, Ph.D., P.E.

¹ Ph.D. Student, Department of Civil and Environmental Engineering and Construction, Howard R. Hughes College of Engineering, University of Nevada, Las Vegas, 4505 S. Maryland Parkway, Las Vegas, NV 89154, USA; PH (702) 885-5028; FAX (702) 895-3936; E-mail: shrest18@unlv.nevada.edu
² Associate Professor, Department of Civil and Environmental Engineering and Construction, Howard R. Hughes College of Engineering, University of Nevada, Las Vegas, 4505 S. Maryland Parkway, Las Vegas, NV 89154, USA; PH (702) 895-3841; FAX (702) 895-3936; E-mail: pramen.shrestha@unlv.edu

ABSTRACT

Departments of Transportation (DOTs) have had a problem in determining cost estimates to maintain road assets so that they can operate at a high level of service. These cost estimates are very crucial during budget planning for road maintenance activities. DOT managers have to plan a budget for road maintenance activities before the beginning of each fiscal year. For this, they need information regarding the conditions of the road assets and the cost to improve the level of service of these assets. The main goal of this study was to build a tool that would assist DOT managers in cost estimation of road improvement programs. Using this tool, DOT personnel enter the conditions of the road assets, using a grading system similar to that used by American Society of Civil Engineers (ASCE) annual ‘report card,’ and enters the cost of the maintenance work needed in order to improve the grade. Once these data are entered into the system, the tool calculates the cost to improve the road assets. This tool links the database with an interactive map using the Geographical Information System (GIS); in this way, managers can view the condition of road assets.

Key words: Tool, Road Asset, Geographical Information System, Road Asset Grade, Budget

INTRODUCTION

The Report Card 2013 for America’s Infrastructures prepared by American Society of Civil Engineers (ASCE 2013) showed that almost 42% of urban highways face traffic congestion problem, resulting in wasting time and fuel and costing approximately an equivalent of $101 billion per year. The report card revealed that the same amount of money per annum was required to maintain roads in current condition and around $170 billion per annum to improve the road from deteriorating. However, federal, state, and local governments are spending less money than required to keep the roads in good condition. That is why the road conditions are getting worse; in fact, the overall grades of the roads have been lowered to ‘D,’ indicating
poor condition.

This study considers that each road in the road network has its own grade, similar to the grading system adopted by ASCE. The grades of the road sections rely on the pavement condition index (PCI), whose value ranges from 0 to 100. The lower the PCI value, the worse the road condition; the higher the PCI value, better the road condition. Depending upon PCI ratings, the Ontario Good Roads Association (OGRA), Canada (2009) prepared a PCI decision matrix for different road types. The decision matrix showed that a PCI range for the time of improvement differed with road types such as freeways, arterials, collectors, and locals. Table 1 shows the grading system based on this matrix for freeways. Similar tables, with different PCI ranges, can be prepared for other road types.

<table>
<thead>
<tr>
<th>PCI Range</th>
<th>Pavement Condition</th>
<th>Grade Assigned</th>
<th>Maintenance Remedies</th>
<th>Example of road activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCI &gt; 85</td>
<td>Excellent</td>
<td>A</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>85 ≥PCI ≥ 76</td>
<td>Good</td>
<td>B</td>
<td>Minor maintenance</td>
<td>Crack sealing</td>
</tr>
<tr>
<td>75 ≥PCI ≥ 66</td>
<td>Fair</td>
<td>C</td>
<td>Preventive maintenance</td>
<td>Partial patching</td>
</tr>
<tr>
<td>65 ≥PCI ≥ 60</td>
<td>Bad</td>
<td>D</td>
<td>Rehabilitation</td>
<td>Overlay + patching</td>
</tr>
<tr>
<td>PCI &lt; 60</td>
<td>Failed</td>
<td>F</td>
<td>Re-constructions</td>
<td>New construction</td>
</tr>
</tbody>
</table>

The upgrade and maintenance costs vary depending upon the spatial location, the grades, pavement types, resources available, and timing of the work. If the unit cost of upgrade and maintenance work can be developed for an individual road or road section to increase the service level of the road, then the total cost of the maintenance and improvement cost can be estimated. This kind of estimate will be helpful for the maintenance manager at the DOT to make the necessary decisions for planning and budgeting works.

The purpose of this study is to make use of open source software for estimating the maintenance and upgrade of roads and then visualizing the roads using a GIS interface. Using open source software avoids any kind of investment of public money to purchase commercial software. Instead, the public money can be used for maintenance and improvement of the deteriorating road networks.

In this study, a tool that has several user-friendly interfaces for its data entry system was developed for cost estimation. Once the system receives the necessary data for estimations, the total cost estimate of maintaining and upgrading the road could be done.

**OBJECTIVES**

Cost estimation plays a great role in determining the feasibility of a project in terms of monetary value. If the available budget does not cover the estimated cost, many difficulties arise in the project. The objectives of this study are:

1) Develop a tool capable of cost estimation to assist DOT offices in the decision-making process for the maintenance and improvement work of roads.

2) Link this tool with GIS interfaces to visualize the condition of roads on a map as well as in Google Earth application.
LITERATURE REVIEW

According to Hassanain et al. (2003), "Any constructed facility can be considered an asset or an investment that needs to be maintained to ensure its optimal value over its life cycle." The authors intended to build a generalized and systematic framework for the asset maintenance and management system. To construct the framework, the authors studied software available in the market (BUILDER, MAXIMO, and RECAP) and used the Integrated DEFinition 0 (IDEF0) process model to discuss the framework.

According to Mizusawa and McNeil (2009), "Asset management systems are decision-support tools designed to support the systematic process of cost-effectively maintaining, upgrading, and operating physical assets." The authors applied:

1) ‘Descriptive analysis’ to study the traffic and asset condition improvement after implementing the Pavement Management System (PMS);
2) ‘Regression analysis’ to find the relationship between the implementation of PMS and the road performance improvement; and
3) ‘Benefit cost analysis’ to determine the benefit of the PMS in terms of monetary value.

The authors used the efficacy, the effectiveness, and the efficiency of the PMS as a basis of benefit quantification.

Noticing the lack of consideration for aspects regarding geotechnical facilities in the asset management system, Bernhardt et al. (2003) strongly advocated for the importance of those aspects. The authors stated that overlooking the importance of embankments and slopes could cause prolonged and expensive maintenance of the other assets in highways. The authors devised decision trees to evaluate what kind of remedies could be taken to tackle the failure of earthen embankments and slopes.

Considering the importance of the decision-making process in estimating the cost of road maintenance work, Shrestha and Pradhanaga (2009) worked on a tool, based on GIS, to assist the prioritization of road maintenance work of the United States Department of Transportation (DOT). The authors used Visual Basic for Applications (VBA) embedded in Arc GIS 9.3 version to create the add-in tool for the Arc Map application. For data storage and retrieval, the authors used a personal geodatabase file system provided by the Arc-GIS application. For the prioritization of the road maintenance projects, the authors adopted three parameters: the pavement condition index (PCI), the unit cost of the resurfacing and rehabilitation, and the traffic volume (count).

The data mining and knowledge discovery (DMKD) technology can be combined with GIS for better decision making in setting priorities for road maintenance and rehabilitation and for investment planning (Zhou et al. 2010). The authors used decision trees to determine the technical feasibility of the rehabilitation program for the road segments. For mapping purposes, the authors used the Arc GIS v. 9.1. The authors concluded that the use of DMKD in association with GIS can speed up the decision making process to select the proper rehabilitation strategy for the road sections.

Cooksey S. R et al. (2011) proposed an Asset Management Assessment Model (AM)^2 to benchmark the asset management tools used by DOTs. The main purpose of (AM)^2 was to explore the major strengths and weaknesses of the asset
management tool being used. The authors noticed that when (AM)² was used, it helped the users to identify and focus the resources and efforts to improve current asset management practices.

Vanier (2001) conducted a study on the question: “why industry needs asset management tools.” The authors claimed that for proper repair, maintenance, and improvement of the existing assets or future assets, the asset management team should consider the following questions:

a) “What do you own?
b) What is it worth?
c) What is the deferred maintenance?
d) What is its condition?
e) What is the remaining service life? and
f) What do you fix first?”

SYSTEM DEVELOPMENT

This study explored in detail the necessary information regarding the asset grading system adopted by the ASCE and the required software for development of this GIS enabled cost estimation tool. Mainly, this study focused on the utilization of the free open-source software that was available online. The necessary software – PostGreSQL (for the database), DotSpatial (an open-source solution project), and Google Earth tools were collected. In addition, the Microsoft (MS) Visual Studio, which had to be purchased from Microsoft Corporation, was available in the computer laboratory of University of Nevada, Las Vegas (UNLV).

This software used the unit cost of the improvement and construction cost indices to estimate the total cost of the road maintenance and upgrades for acquiring the service level of excellent-grade road. Xu and Moon (2013) mentioned the importance of the construction cost index for estimating a construction budget and assessing the risk in resource and construction planning. The construction cost index data published by Engineering News Records (ENR) were collected from web sites for testing purposes. Similarly, a list of states in the U.S. and the list of counties were obtained from the internet. For the sample computations, the tentative unit cost was used for maintenance and upgrading.

Software architecture

Usually, any GIS tool should have three components; a database, a map interface, and an application interface to interact with the database and the map component. The software used in this study has these components. It uses PostGreSQL (available on http://www.postgresql.org/) as the database tool because of its popularity for the open-source object-relational database system. However, to work properly with spatial data information, a plug-in known as PostGIS (http://postgis.net/install/) was required to be installed separately. For GIS interfaces, the latest project DotSpatial 1.4 version was used, which was freely available online on http://dotspatial.codeplex.com/); moreover, Desktop Google Earth version 7.1.1.1888 was used to explore the roads in detail. The latest version of Google Earth can be downloaded from web site http://www.google.com/earth/index.html. The relationship between the components is shown in Figure 1.
Because the DotSpatial project uses the Microsoft Visual Studio, the 2012 version available in laboratory at UNLV was used. The Microsoft Visual Studio C# provided the required platform for software development. The DotSpatial project interacted with the PostGIS database for data storing and retrieval, displayed road networks in GIS interfaces, and produced Keyhole Markup Language (KML) file to locate the road in Google Earth application. Further, the DotSpatial project played a mediator role between the database and mapping functionalities.

![GIS Enabled Cost Estimation](image)

**Figure 1. Components in the GIS enabled cost estimation tool.**

**Database concept**
Utilization of the open-source database system, PostGreSQL, is a good aspect of this software. Even though the database is free, the database has all the features required for a relational database and the GIS functionality is included with the PostGIS add-in. Therefore, the PostGIS combined with PostGreSQL gives the perfect combination that meets the necessary requirements for a GIS based application development. For a simple application development to find the cost of road maintenance and improvement, the minimum required number of tables and their relationship are shown in Figure 2. Because of these relationships, a data row in one table is tied to data rows in another table.

![Database Tables](image)

**Figure 2. Basic database tables for storing the data input.**
The road links were saved in the database with their unique identification numbers, along with the necessary details, as shown in the tables’ structure in Figure 2. For testing purposes, road links were obtained from a website for Las Vegas (http://www.mapcruzin.com/free-united-states-shapefiles/free-nevada-arcgis-maps-shapefiles.htm). However, such details as start chainage, end chainage, and county names were not available. A GIS field, ‘thegeom,’ stored the geometry of the road link, which was required to display the road on the map. Data for other tables, including ‘States,’ ‘County,’ and ‘Grades’ were prepared as default data during the software development. The data required for ‘unitCost’ and ‘upgradeWorks’ tables were entered using the software interfaces, which are explained in Software Details section of this paper.

The unit cost of upgrade and maintenance varies, based on the type of upgrade and maintenance work and the road type. The field ‘unitCostFA’ in the table ‘unitCost’ is for the unit cost of upgrade and maintenance to improve the roads from the current failing grade status of ‘F’ to an excellent grade status of ‘A.’ Similarly, the field ‘unitCostDA’ is for the unit cost of upgrade and maintenance to upgrade from grade ‘D’ to grade ‘A’. Other fields store various other unit costs, based on road types. The ‘costIndex’ table stores the annual indices for average construction costs by year, states, and cities of the U.S.

Software details
Because of its strong features, such as the GIS interfaces available in the DotSpatial project, the Microsoft Visual C# environment was chosen as software development platform. The DotSpatial project, in association with PostGIS, provided the necessary platform for GIS mapping and programming environment. With the map interface provided by DotSpatial application, the interactive working with data and map was possible; further, it helped to understand the map functions. As shown in Figure 3, the road networks were loaded to the map from the PostGIS database, and the roads assigned proper symbols in order to have a clear look at the road network.

![Figure 3. Sample GIS interface.](image-url)
This application allowed loading as many map layers as required. Once the layers were loaded, the details of the layers could be checked on the map as well as in the attribute table, as shown in Figure 3. The attribute table helped displaying the properties associated with each road in the layer. To explore the map properly, the map interfaces had such commands as zoom in, zoom out, pan, zoom to full extent, and other relevant commands. Each road in the road networks could be displayed with its name labeled as text on the map.

Another interesting feature in this application is its ability to create KML files. This tool has an option to save the selected road feature in the form of a KML file. Then, the KML file can be loaded to a Google Earth application by double clicking the file in Windows Explorer, and current conditions of the road can be studied in detail. This step can be made automatic by linking this application with Google Earth and displaying the road in that application instantly. Figure 4 shows the KML file loading in Google Earth; the white line represents the road saved to the file.

![Figure 4. Loading of a KML file in Google Earth.](image)

All the necessary data was saved in the database by using several interfaces available in this application. First, the section of a road link to be upgraded and maintained was identified; then, the current grade of the road and the unit cost for reference city was assigned. By default, the grade to be achieved was grade ‘A.’ The estimation of the upgrade and maintenance was achieved with following steps.

a) Determine the city name, the current grade, the road type, and the newly targeted grade of the selected road to be upgraded and maintained. Also find the reference city name for deriving unit cost.

b) Query the ‘unitCost’ table to get the unit cost of upgrade and maintenance of the specified road type in the latest year saved for the reference city.
c) Obtain the construction cost indices for the reference city and target city. Location adjustment (Peurifoy and Oberlender 2001) is done using Equation 1, assuming City A represents the reference City and City B represents the selected city.

\[
\text{Unit cost in city } B = \frac{\text{Cost index for city } A}{\text{Cost index for city } A} \times \text{Unit cost in city } A \tag{1}
\]

d) The inflation and deflation of cost is applied to the unit cost, based on the equivalent interest rate \((i)\), as calculated in Equation 2.

\[
\frac{\text{Cost index for year } y_1}{\text{Cost index for year } y_2} = (1 + i)^n \tag{2}
\]

Where cost indices are based on ENR, \(i\) is the interest rate and \(n\) is the number of years between the year \(y_1\) and \(y_2\). From Equation 2, the value for \(i\) is calculated.

e) The interest rate \(i\) is applied to the base unit cost, considering the gap between the base year and year that the construction work was done (e.g., \(n1\) years). The unit cost calculated by Equation 3 gives the current unit cost for the target location.

\[
\text{Current unit cost in city } B = \text{Base year unit cost in city } B \times (1 + i)^n \tag{3}
\]

f) The database table is queried to obtain the lane width and length of the concerned section. Then, the product of the lane width and length of section gives the total area, as shown in Equation 4.

\[
\text{Total area in square meters (SM)} = \text{lane width in meters} \times \text{length of the road section in meters} \tag{4}
\]

g) Equation 5 is used to calculate the cost for upgrading and maintenance in dollars per kilometer per lane.

\[
\text{Cost per kilometer-lane (Cost/km lane)} = \frac{\text{unit cost/SM} \times \text{total area in SM}}{\text{length of road section in kilometers}} \tag{5}
\]

h) Now the total cost of the road upgrade and maintenance is calculated with help of equation 6.

\[
\text{The total cost estimate} = \text{Cost/km lane} \times \text{Total length of road in km} \times \text{Number of Lanes} \tag{6}
\]

This application has capabilities to perform all the steps needed to find the
cost of upgrading and maintaining the road. The necessary data are entered with the help of data entry forms shown in Figure 5 and Figure 6.

![Figure 5. Data entry table for unit cost of upgrading and maintenance works](image)

![Figure 6. Data entry table showing roads to be upgraded and maintained.](image)

Once all the necessary data are entered through data entry forms, the calculation is performed for all roads individually. A summary of the calculation is presented in a separate output table, shown in Figure 7.

![Figure 7. Sample calculation output showing cost estimation](image)

**CONCLUSIONS**

With help of the application developed during this study, users can compute an estimate for the cost per kilometer-lane of maintaining and upgrading a road to the desired grade. The input and output interfaces help to enter the data and visualize the result graphically. If implemented in DOT offices, this application will provide the DOT maintenance manager with two main functions: estimating the cost of road improvement and visualizing the road in GIS interface as well as in a Google Earth application.

The achievement perceived while doing this study was the use of open-source software, which is freely available online. Because this system was designed using open-source projects, anybody can conduct research to develop this application further. Eventually, by promoting the use of open-source projects, huge amounts of
the public money otherwise that would be spent on purchasing commercial software could potentially be saved. The money saved could be invested in construction work of public infrastructures.

Further development of this tool can be done by incorporating the options for a budget planning tools for road upgrade and maintenance work. If we could do that the cost estimate output of this tool will have immediate use in budget planning. Any progress made on the road upgrade and maintenance work could be recorded and could be compared with actual budget planned. The progress recorded through monitoring process also could be presented on map.

ACKNOWLEDGEMENT

The authors would like to acknowledge the great contribution of all the software developers who are working on development projects for open-source software. In particular, the authors want to thank the project developer teams of DotSpatial, PostGIS, PostGreSQL as well as all the providers of free websites and software applications.

REFERENCES


