Pavement Management Systems Application with Geographic Information System Method

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(Alınış / Received: 08.07.2015, Kabul / Accepted: 10.02.2016, Online Yayınlanma / Published Online: 15.04.2016)

Keywords
Pavement management systems  
Geographic information systems  
Fuzzy logic  
Genetic algorithm

Abstract: In this study, performance models were developed. Software in Visual Basic programming language was used for the developed model. Using the software, both the present condition of the pavement can be examined and future performance based on expected traffic values can be predicted. So, the software can be used at both network and project level. Cost and benefit values taken from the literature were used in determining the cost-benefit ratio. Using the genetic algorithm approach, a computer program in Visual Basic programming language was written. Using the model developed, a five-year maintenance and rehabilitation program can be planned for a given database considering budget restraints. The developed models were merged by writing Geographic Information System (GIS) software in order to show the effectiveness of models and adopt the models into a GIS. For this purpose, a case study of GIS was exposed. The control of the overall system can be applied in addition to the application of the model at network level. The developed software allows data to be transferred to the database, analyses and different scenario applications for showing GIS results.

1. Introduction

In Turkey there are two institutions working on highway transportation. These are the General Directorate of Land Transportation, and the General Directorate of Highways under the Ministry of Transport and Communications. In Turkey, the land routes are divided into four classes: motorways, state highways, provincial roads and rural roads. The planning, construction and administration of motorways, state highways and provincial roads are the responsibility of the General Directorate of Highways. On the other hand the responsibilities of the General Directorate of Land Transportation are to carry out legislative arrangements regarding railways and land transportation, to accede to the treaties and make provisions for compatibility purposes with

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other transport services, and to provide developments [1].

Many of the roads in the Turkish highway network were designed and constructed according to the demands of their periods. Thus, they have become unable to carry the increasing traffic loads, especially heavy vehicle traffic nowadays. In addition to this, overloading of heavy vehicles cause to significantly decreases to service life, estimated at 20 years, of the state highways [2].

In Table 1. Given the Turkey’s road network lengths according to surface types.

<table>
<thead>
<tr>
<th>Road Types</th>
<th>Asphalt</th>
<th>Concrete</th>
<th>Seal Coat</th>
<th>Cobblestone</th>
<th>Stabilize</th>
<th>Unbound</th>
<th>Others</th>
<th>Total Length (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorways</td>
<td>2155</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>2155</td>
</tr>
<tr>
<td>State Highway</td>
<td>13446</td>
<td>17415</td>
<td>72</td>
<td>67</td>
<td>29</td>
<td>251</td>
<td>3128</td>
<td>0</td>
</tr>
<tr>
<td>Provincial Roads</td>
<td>2476</td>
<td>26862</td>
<td>201</td>
<td>824</td>
<td>570</td>
<td>1541</td>
<td>3247</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>18077</td>
<td>44277</td>
<td>273</td>
<td>891</td>
<td>599</td>
<td>1792</td>
<td>6590</td>
<td>9</td>
</tr>
</tbody>
</table>

Maintenance and improvement costs of the Turkish highway network continue to increase as new state roads and motorways are added and significant management problems arise. Increase in freight traffic adds to this, so, the need for new facilities and maintenance and improvement of present state highways has become more important [2,4].

Airport and highway networks are one of the most important economic activities in modern industrialized societies that constitute an enormous investment of public funds [5]. Maintaining the roadway infrastructure takes great amounts of time and money. Billions of dollars are invested, annually, in road maintenance to ensure the mobility of people and goods. However, deteriorating road conditions, increasing traffic loading, and shrinking funds have presented a complex management challenge to the maintenance and rehabilitation process. It requires evaluating pavement network conditions, deciding on maintenance strategies, setting rehabilitation priorities, and making investment decisions, which together make up a pavement management system (PMS). The purpose of implementing a PMS is to identify maintenance needs, control costs, allocate funding, support decision making, and maintain good pavement conditions under the constraint of limited funds [6,7].

Recent developments in computer hardware and software such as CD-ROM, digital cameras, and image processing systems have enabled pavement condition surveys to be conducted much faster and more accurately than with the manual visual inspection procedure of the past. In addition, PMS can be enhanced with new features and functionality to perform pavement management operations and create maps of pavement condition by using a geographic information system (GIS) [6].

Nowadays, as GIS is increasingly used in public authorities, there is a growing trend toward integrating PMS data into the GIS. With technological advances in computer hardware and software, this integration is becoming more realistic. Advantages of such integration include flexible database editing and the ability to visually display the results of database queries, statistics and charting, pavement management analyses on a map of the highway network, and being able to view network conditions through dynamic colour-coding of highway sections, and access sectional data through the graphical map interface [8,9].

A well-designed geographic information system (GIS) provides a platform on which all aspects of the PMS process can be built. The resulting system, GIS/PMS, represents a significant enhancement of all aspects of the PMS process. A variety of spatially integrated data is important for pavement management decision making. GIS technology is shown to be the most logical way of relating these diverse, but relevant, data. The components include data collection, preliminary data analysis and interpretation, system assessment, determination of strategies, project identification and development, and project implementation. Each of these stages in the PMS process is enhanced by GIS technology. Looking at the PMS process in its entirety leads to the enumeration of a set of functions to be embedded in the GIS platform that is required for effective GIS/PMS. These functions include thematic mapping, a flexible data base editor, formula editing, statistics, charting, matrix manipulation, network generation, models and algorithms, and hooks to external procedures [10].

The Pavement Management System (PMS) studies in Turkey were begun in 1994 by the Republic of Turkey General Directorate of Highways by means of cooperation with the Canadian company Pavement Management System Limited (PMSL). The aims of this system, designed in two stages, were to a programmed develop as applicable and developable, compatible with the conditions and needs of Turkey, and to provide technology transfer related to this issue. In the first stage, a network-scaled management system was constructed in the national highways around Ankara, and in the second stage, a system conducted in a nation-wise manner with the help of funding, which were thought to be received from the World Bank. However, the second stage plans were temporarily cancelled due to economic crises. In the following years, unevenness measurements were carried out, by
means of a profilometer, on the asphalt concrete roads
in the General Directorate of Highways 5th Region,
whose center is located in Mersin, and maintenance-
repair strategies were developed and cost-efficiency
values were found for these roads. However, the
project was disregarded since the unevenness, caused
by settlements from wheel traces, could not be
properly measured, even though this is one of the most
common unevenness sources in our country [11,12].

In this study, performance models were developed.
Software in Visual Basic programming language was
written for the developed models. Using this software,
both the present condition of pavement can be
examined and future performance based on expected
traffic values can be predicted. So, the software can be
used at both network and project level. Cost and
benefit values taken from the literature were used in
determining the cost-benefit ratio. Using the genetic
algorithm approach, a computer program in Visual
Basic programming language was written. Using the
model developed, a five-year maintenance and
rehabilitation program can be planned for a given
database considering budget restraints. The
developed models were merged by writing GIS
software in order to show the effectiveness of models
and adopt the models into a GIS. For this purpose a
case study of GIS was performed.

2. Material and Method

2.1. Pavement management system

The pavement management concept was first
conceived of in the mid-1960s to organize and
coordinate the activities involved in achieving the best
value possible with the available funds [13]. In
response to the growing need for highway
rehabilitation and maintenance on the one hand and
shrinking resources on the other, there has been an
increased interest in developing a formal management
approach to optimize the utilization of highway
construction and maintenance resources. The specific
component of this approach related to pavement is
termed “pavement management system”
[14,15,16,17].

A PMS has been defined as a “set of tools or methods
that can assist decision makers in finding cost-
effective strategies for providing, evaluating, and
maintaining pavements in a serviceable condition”
[18,2,19].

A PMS typically includes several modules. For
example, Figure 1 shows a generic PMS with five
modules: a road network database, a quality
evaluation system (also referred to as need analysis),
a costs model, pavement performance models and a
maintenance strategies optimization system [20].

Figure 1. Structure of a PMS [20]

PMS provides a systematic process for collecting,
managing, analyzing, and summarizing pavement
information to support the selection and
implementation of cost-effective pavement
construction, rehabilitation, and maintenance
programs [18].

Pavement management includes all activities involved
in planning and programming, design, construction,
maintenance and rehabilitation of a pavement portion
of a public works program. A PMS is a set of tools or
methods that assists decision makers in finding the
optimum strategies for providing and maintaining
pavements serviceable conditions over a specified
time period. The function of a PMS is to improve the
efficiency of decision making, provide feedback on the
consequences of the decision, provide coordination of
activities of an agency and ensure consistency of
decisions within the same agency at the different
levels of management [21].

Pavement management comprises two different
operating levels which are “network level” and
“project level” [22,17,23]. “Network-level” analysis
tools support planning and programming decisions for
the entire network or system. A PMS usually includes
tools to evaluate the condition of the pavement
network and predict pavement performance over
time, identify appropriate M&R projects, evaluate the
different alternatives to determine the network needs,
prioritize or optimize the allocation of resources to
generate plans, programs, and budgets and assess the
impact of funding decisions.

“Project-level” analysis tools are then used to select
the final alternatives and to design the projects
included in the work program. The pavement
management cycle then continues with the execution
of the specified work. Changes in the pavement as a
result of the work conducted, as well as normal
deterioration, are periodically monitored and fed back
into the system.

From an asset management perspective, network-
level goals and available budgets are defined by
higher-level strategic decisions that set the overall goals for system performance and the policies of the agency. PMS produce reports and graphic displays that are tailored to different organizational levels of management and executive levels, as well to the public [18,24].

2.2. Developed performance prediction models

Pavement prediction performance models are used at both the network and project level to analyze the condition and determine maintenance and rehabilitation (M&R) requirements. At the network level, they are used for condition forecasting, budget planning, inspection schedule, and working planning. At the project level, they are used to select rehabilitation alternatives to meet expected traffic and climate conditions, and to perform life-cycle cost analysis to compare various M&R alternatives. Many techniques are available for developing pavement deterioration models. They include straight line extrapolation, regression, mechanistic-empirical, polynomial constrained least square, S-shaped curve, probability distribution, and markovian [25].

Previous researchers have explored numerous pavement performance prediction models in the past [26,27,28,29,30,31,32,33].

In this study, Artificial Neural Networks, Multiple Regression, Fuzzy Logic and Genetic Expression Programming methods were used in the assessment of International Roughness Index (IRI) value, which was chosen as the indicator of the performance. The input data were taken into consideration in these models are among the most important safety parameters affecting pavement service life.

In the test setting of the modelling, carried out by using Artificial Neural Networks, with eight and one input values, 0.94 $R^2$ and 0.96 $R^2$ values were obtained, respectively. In the multiple regression model, on the other hand, 0.918 $R^2$ and 0.89 $R^2$ values were obtained for eight-input-model and one-input-model, respectively. In the Genetic Expression Programming (GEP) model, these values were 0.80 $R^2$ and 0.91 $R^2$. By using the Adaptive Neuro-Fuzzy Inference Systems (ANFIS), a 0.70 $R^2$ value was obtained for an eight-input-model and 0.96 $R^2$ for a one-input-model. When all these values are compared, the methods giving the highest correlation are seen to be ANN and ANFIS models, and one-input-models are more successful than the others.

2.3. Cost benefit analysis in flexible pavements by using genetic algorithm method (Budget Distribution)

One of the most important issues in pavement management systems is the destruction of the limited budget. In this study, the deformations in the asphalt concrete pavements, methods of repair, traffic accidents and their costs (material damage, injuries and death), and vehicle operational costs were all determined separately for our country. Within the limits of the available budgets, methods of repair were determined by means of an optimization study to maximize benefit, by using performance, AADT, accident cost values and inflation rate.

It is difficult to determine a repair budget program for flexible pavements in the planning stage, during the analysis period. In addition, the changes in service life-cycle costs are sensitive against the budget changes, with the increasing numbers of projects. In this study, an optimization system was applied by using the genetic algorithm method for the aim of considering these uncertainties in the pavement repair programs. Furthermore, a new objective function was developed and maintenance and repair strategies were handled independently from resources, and according to service abilities. A computer program was developed in order to solve the models. The programming language used for this aim was Visual Studio. In this computer program, a genetic algorithm method was used.

In Figure 4, the user interface, belonging to one of the solutions made by the mentioned computer program is shown. In addition, the user is able to change the accident costs, and maintenance-repair method costs and additional service life values.

2.4. Developed geographical information system software for pavement management systems

In this study, the models developed by means of developed GIS software were united on a single platform in order to adapt the developed models to a Pavement Management System, and to demonstrate the workability of these models. For the GIS software, ESRI® MapObject software was used. The developed software includes the pavement inventory entrance date, performance assessment, inquiry, and reporting characteristics.
The developed software is basically composed of three parts. The Windows-based interface, web-based interface and a shared database are the parts forming the system (Figure 3). The most important part in terms of the system integrity is a database. The database is shared, because in case of a data change or data addition. The data can be seen and processed simultaneously from another location. This feature is time saving.

![Figure 3. Structure of the developed geographical information system](image)

By using this web-based interface, the users (sub offices) can digitalize the changes or additions. Also, they can realize data entrance on the internet. The changes are directly saved on the database itself (Figure 4).

![Figure 4. Data entrance and arrangement screen in the web-based interface](image)

With the help of the developed Windows-based interface, the authorized users can access the program and all the information in the database, can be carried out analyses by using the data located in the database, and re-register to the system. With this program, the data are taken from a shared database. A Windows-based computer program was developed for the aim of data analyses and their solutions. The programming language used for the development of the mentioned computer program is Visual Basic, and the design was carried out by using Microsoft Visual Studio®. In Figure 5, the user interface belonging to

![Figure 5. Main Screen of the Developed Windows-Based Interface Software](image)

2.5. Application and a case study

Here, an exemplary work was carried out for the aim of uniting the developed models in this study on a single platform, adapting them to a Pavement Management System and indicating the workability of these models. In this study, the data belonging to a certain region entered from the Web-based interface were analyzed and necessary information was presented to the authorized users in a schematically-digital way.

The General Directorate 4th Region, whose center is in Ankara, was chosen as the network. In 1994, the first PMS was also carried out in this region by Pavement Management Systems Limited. Highways on the indicated network were digitalized and transferred to the computer environment. In addition, Turkey provincial borders were also digitalized as a template and these layers were viewed on top of each other. The selected network was divided into different sections, defined by the General Directorate of Highways (Figure 6).

![Figure 6. Highway network map of the pilot region](image)
The inquiry feature was added to the developed software which is one of the indispensable components of GIS and PMS. For this aim, a sub-program was developed. A possible inquiry example is shown in the system (Figure 7 and Figure 8).

![Figure 7. An exemplary inquiry screen in the user interface](image)

![Figure 8. Assessed IRI values for 2012](image)

A reporting feature, which is another important component of GIS and PMS, was also added to the developed software. For this aim, a programme was developed. Using this software, the inquiry results can be reported, printed, transferred to other files and saved. An exemplary reporting screen in the user interface was shown in Figure 9.

![Figure 9. An exemplary reporting screen in the user interface](image)

With the help of the developed sub-program, the statistical information regarding the numerical data can be viewed. In Figure 10, an exemplary statistical evaluation is shown.

![Figure 10. Screen of the statistical sub-program](image)

The user is able to make an inquiry at the non-graphical database, according to graphical data definitions. The database of an object on the map can be viewed, changed, and saved (Figure 11 and Figure 12).

![Figure 11. Result of a definition example](image)
4. Discussion and Conclusion

In this study, the developed models were merged by writing GIS software in order to show the effectiveness of models and adopt the models into a GIS. For this purpose a case study of GIS was exposed. The control of overall system can be applied in addition to application of the model for network level. The developed software permit the data transfer to database, analyzes and different scenario applications for showing results for GIS. All purposes were reached in the case study.

Acknowledgment

This research supported by The Scientific & Technological Research Council of Turkish (TUBITAK, Project number: 108 M 052) and Süleyman Demirel University (SDU, BAP, Project number: 3122 D 12).

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