

Pavement Management Systems Application with Geographic Information System Method

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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.

Coğrafi Bilgi Sistemleri Yöntemi ile Üstyapı Yönetim Sistemi Uygulaması

Anahtar Kelimeler

Üstyapı yönetim sistemi
Coğrafi bilgi sistemleri
Bulanık mantık
Genetik algoritma

Özet: Bu çalışmada performans modelleri geliştirilmiştir. Geliştirilen modeller için Visual Basic programlama dili kullanılarak bir yazılım oluşturulmuştur. Bu yazılım ile hem mevcut durum hem de beklenen trafik yükü altında oluşacak durum tahmin edilmiştir. Dolayısıyla bu yazılım hem ağ düzeyi hem de proje düzeyinde kullanılabilir. Literatürden alınan maliyet ve fayda verileri fayda/maliyet oranı için kullanılmıştır. Genetik algoritma yaklaşımı kullanılarak Visual Basic programlama dilinde program yazılmıştır. Geliştirilen model kullanılarak beş yıllık bakım-rehabilitasyon planı oluşturulmuştur. Modellerin etkinliğini göstermek için ve modelleri bir Coğrafi Bilgi Sistemi (CBS) veri tabanına entegre etmek amacıyla geliştirilen modeller CBS yazılımında birleştirilmiştir. Bu amaçla CBS yazılımı kullanılmıştır. Geliştirilen yazılım verilerin veri bankasından çekilmesine, analiz edilmesine ve CBS üzerinden farklı senaryoların simülasyonuna olanak sağlamaktadır.

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

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 1. Turkey's Road Network Lengths According to Pavement Types [3]

Road Types	Asphalt Concrete	Seal Coat	Cobblestone	Stabilize	Unbound	Others	Total Lengths (km)
Motorways	2155	--	--	--	--	--	2155
State Highways	13446	17415	72	67	29	251	31280
Provincial Roads	2476	26862	201	824	570	1541	32474
Total	18077	44277	273	891	599	1792	65909

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].

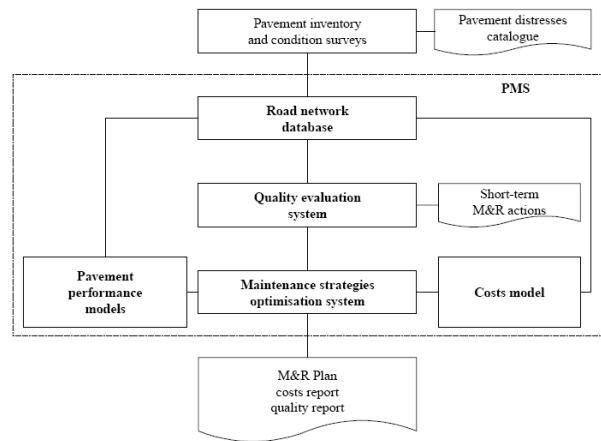


Figure 1. Structure of a PMS [20]

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 R² and 0.96 R² values were obtained, respectively. In the multiple regression model, on the other hand, 0.918 R² and 0.89 R² values were obtained for eight-input-model and one-input-model, respectively. In the Genetic Expression Programming (GEP) model, these values were 0.80 R² and 0.91 R². By using the Adaptive Neuro-Fuzzy Inference Systems (ANFIS), a 0.70 R² value was obtained for an eight-input-model and 0.96 R² 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.

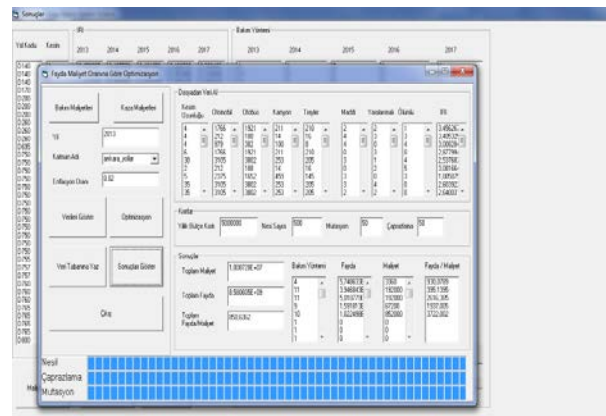


Figure 2. User interface screen of the developed program

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.

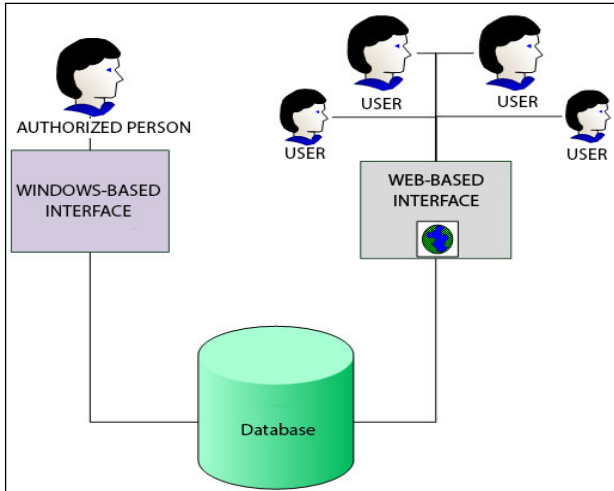


Figure 3. Structure of the developed geographical information system

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).

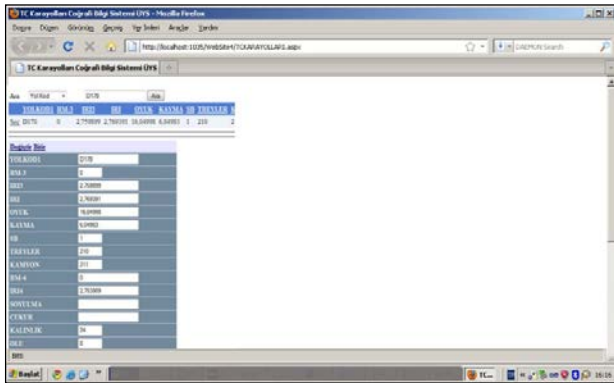


Figure 4. Data entrance and arrangement screen in the web-based interface

With the help of the developed Windows-based interface, the authorized users can be 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

one of the solutions made by the mentioned computer program was shown. In addition, the user is able to change the accident costs, and maintenance and rehabilitation method costs and additional service life values.

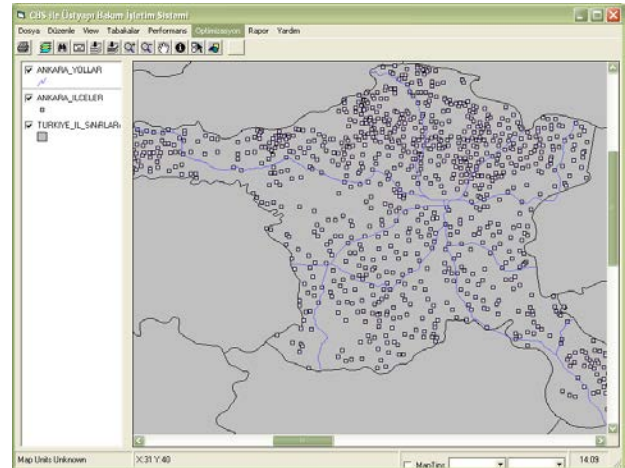


Figure 5. Main Screen of the Developed Windows-Based Interface Software

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).

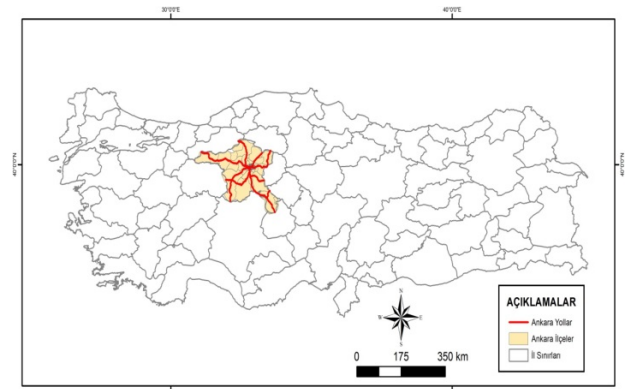


Figure 6. Highway network map of the pilot region

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).

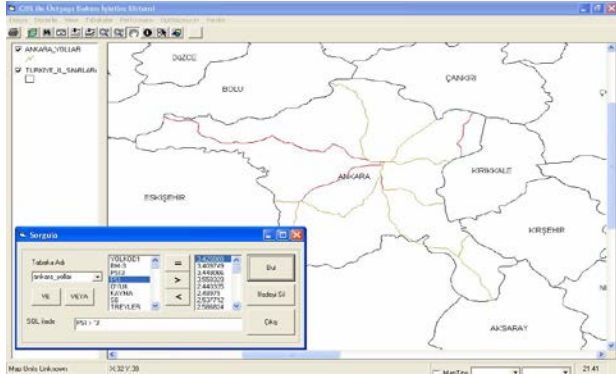


Figure 7. An exemplary inquiry screen in the user interface

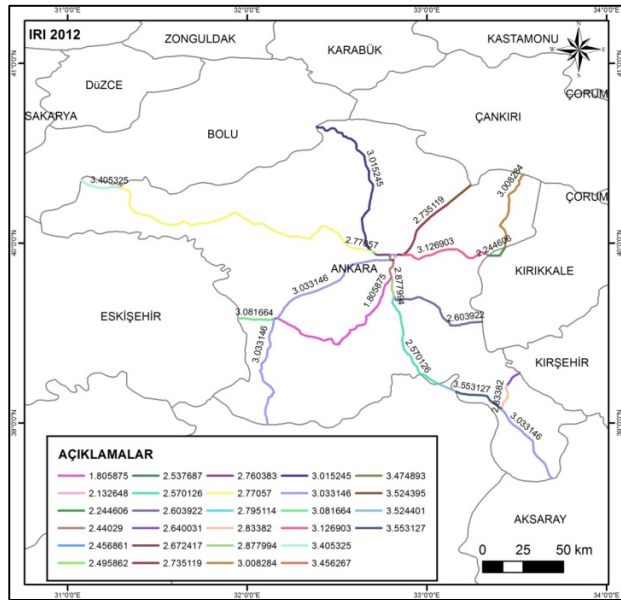


Figure 8. Assessed IRI values for 2012

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. Exemplary reporting screen in the user interface was shown in Figure 9.

YOLKODU	KESIM	PSI	BY-1	BM-1
D140	1	3,456267	5	2590
D140	2	3,405325	13	168000
D140	3	3,008284	2	960,0001
D170	2	2,877994	7	5880
D200	1	2,537687	12	745500
D200	2	3,081664	2	480
D200	3	1,805875	9	6300
D260	1	2,603922	6	79625
D260	2	2,640031	8	83300
D260	3	2,570126	10	115500
D695	1	2,83382	7	29400
D750	1	3,553127	8	16660
D750	2	3,033146	14	212800
D750	3	3,033146	12	124250
D750	4	2,735114	11	18300
D750	5	2,44029	5	29137,5
D750	6	3,033146	8	11900
D750	7	2,735119	8	7140
D750	8	2,735119	10	15400
D750	9	2,735119	7	1960

Figure 9. An exemplary reporting screen in the user interface

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.

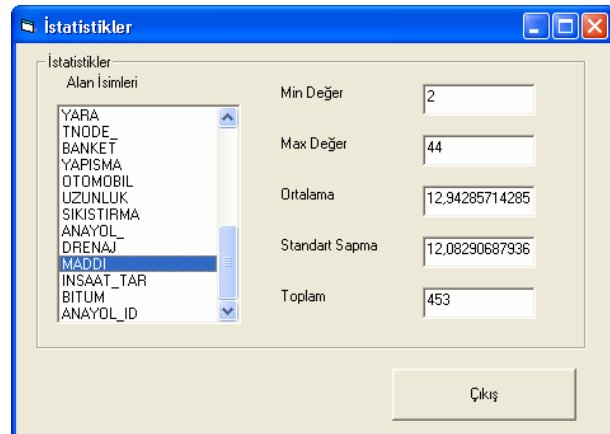


Figure 10. Screen of the statistical sub-program

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).

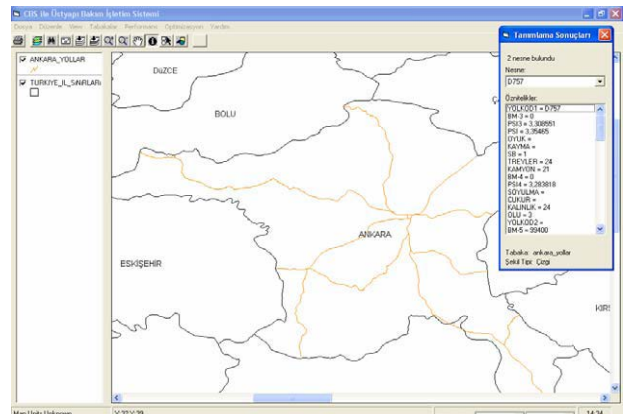


Figure 11. Result of a definition example

No	BM 3	PSI3	PSI	ÖYÜK	KAYMA	SB	TREYLER	KAMYON	BM 4
1	0	3.389465	3.426998			1	315	216	0
2	0	3.374138	3.407949			1	315	216	0
3	0	3.403614	3.440066						0
4	0	3.534431	3.568329						0
5	0	1.434108	2.440335						0
6	0	2.362717	2.489379						0
7	888750	2.419478	2.537712						0
8	134750	2.470345	2.566324						0
9	0	2.588858	2.705208						0
10	0	1.885482	1.897777						0
11	1110250	2.266200	2.620546						0
12	0	1.948794	2.134574			1	899	1126	0
13	0	2.736557	2.810025			1	899	1126	0
14	47800	2.559196	2.559196			1	472	1009	0
15	0	2.868168	2.868598			1	472	1009	1200
16	1943	2.572144	2.656932			1	472	1009	0
17	980	2.572144	2.656932			1	472	1009	0
18	0	2.572144	2.656932			1	472	1009	0
19	0	2.572144	2.656932			1	472	1009	0
20	0	2.868168	2.868598			1	472	1009	0
21	0	2.868168	2.868598			1	472	1009	0
22	0	2.868168	2.868598			1	472	1009	0
23	0	2.868168	2.868598			1	472	1009	0
24	0	2.639466	2.796332			1	695	752	0
25	0	2.451554	2.463939			1	695	752	0
26	0	3.308551	3.354865			1	24	21	0
27	0	2.947288	2.976291			1	12	150	0
28	0	1.662312	1.106262			1	24	21	0

Figure 12. User interface for attribute display References

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.

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References

[1] Aslan. L., 2009, "Türkiye'de ulaştırma sektörünün gelişmesinde devletin yeri ve önemi," Yüksek Lisans Tezi, Dokuz Eylül Üniversitesi Sosyal Bilimler Enstitüsü, 130s, İzmir (in Turkish).

[2] Iyınam. S., Ergun. M., and Iyınam AF. Modeling of state highway pavement maintenance work. Scientific Research and Essays. Vol. 5(21), Available online at <http://www.academicjournals.org/SRE>, 4 November, 2010, pp. 3201-3205.

[3] KGM, 2015., "Information of Road Network", General Directorate of Turkish Highways <http://www.kgm.gov.tr/SiteCollectionDocuments/KGMdocuments/Istatistikler/DevletliYolEnvanter/SatihYolAgiUzunlugu.pdf>, Accessed September 01, 2015.

[4] KGM, 1994, "Pavement Management System Planning and Pilot Project Work, General

Directorate of Turkish Highways," Technical Research Department, Ankara, Turkey.

[5] Ismail. N., Ismail. A., Atiq R., An "Overview of Expert Systems in Pavement Management," European Journal of Scientific Research, Vol:30 No:1, 2009, pp.99-111.

[6] Lee, H.N., S. Jitprasithsiri, H. Lee, and R.G. Sordic, "Development of a Geographic Information System-Based Pavement Management for Salt Lake City," Transportation Research Record 1524, Transportation Research Board, National Research Council, Washington, D.C., 1996, pp. 16-24.

[7] Zhang, Z., S.G. Smith, and W.R. Hudson, "Geographic Information System Implementation Plan for Pavement Management Information System: Texas Department of Transportation," Transportation Research Record 1769, Transportation Research Board, National Research Council, Washington, D.C., 2001, pp. 46-50.

[8] Parida M., 2005, "Enhancing pavement management systems using GIS", Transport 158, Issue TR2, Rookee, India.

[9] Elhadi. H.M.A., 2009, Royal Institute Of Technology GIS, A tool for pavement management, Master's of Science Thesis in Geoinformatics, Department of Urban Planning and Environment, School of Architecture and the Built Environment Royal Institute of Technology (KTH), 51s, Sweden.

[10] Neelam, Jain., Nanda, P.K., Durai, B.K., Prasada, Rao., 2003, Geographical Information System for Pavement Management System, en development.net (Ed.). Map Asia Conference 2003, Transportation. Kuala Lumpur, Malaysia.

[11] Ay, S., 2001, "Antalya Bölgesindeki Devlet Yollarının Üstyapı Performanslarının Analizi ve İyileştirme Çalışmaları," Yüksek Lisans Tezi, AÜ Fen Bilimleri Enstitüsü (in Turkish).

[12] Kırbaş U., 2007, Example of Pavement Management System and the Beşiktaş District and Research on the Application, Yıldız Technical University, Institute of Science, Master of Science Thesis, 168s, Istanbul.

[13] Karan MA, Haas R, Walker T. Illustration of pavement management: from data inventory to priority analysis. Transport Res Rec 1981;814:22-8.

- [14] Rada GR, Perl J, Witczak W. Integrated model for Project level management of flexible pavements. *J Transport Eng* 1985;112(4): 381-99.
- [15] Tavakoli A, Lapin ML, Ludwig F. PMSC: pavement management system for small communities. *J Transport Eng* 1992;118(2):270-81
- [16] Terzi. S., 2006, "Modeling the Pavement Present Serviceability Index of Flexible Highway Pavements Using Data Mining", *J. Appl. Sci.* 6(1): 193-197.
- [17] Kırbaş. U., and Gursoy, M., Developing the basics of pavement management system in Beşiktaş district and evaluation of the selected sections. *Scientific Research and Essays. Vol. 5(8)*, Available online at <http://www.academicjournals.org/SRE>, 18 April, 2010, pp. 806-812.
- [18] NCHRP, SYNTHESIS 335, Pavement Management Applications Using Geographic Information Systems, A Synthesis of Highway Practice, National Cooperative Highway Research Program, Transportation Research Board, Washington, D.C., 2004, 66 pp.
- [19] AASHTO 1990, "Guidelines for Pavement Management Systems," American Association of State Highway and Transportation Officials, Washington, D.C., 45 pp.
- [20] Ferreira, A., Picado-Santos. L., Wuc. Z., and Flintsch. G., "Selection of pavement performance models for use in the Portuguese PMS," *International Journal of Pavement Engineering* Vol. 12, No. 1, February 2011, pp. 87-97.
- [21] Haas, R., Hudson, W. R., Zaniewski, J., 1994, *Modern pavement management*.
- [22] Hergüner, A.T., Açar, E., 2010. Türkiye Otoyol Ağı İçin Üstyapı Performans Tahmin Modellerinin Geliştirilmesi, *İtü dergisi/d Mühendislik* 9(6), 105-113
- [23] Shahin, MY., 2002, *Pavement Management for Airports, Roads and Parking Lots*. Kluwer Academic Publishers, Massachusetts, U.S.A.
- [24] Flintsch, G.W., "Soft Computing Applications in Pavement and Infrastructure Management: State-of-the-Art" , 82nd Annual Meeting of the Transportation Research Board, Washington, D.C., Jan. 12-16, 2003 (preprint 03-3767).
- [25] Shahin, M.Y., 1994, "Pavement Management For Airport, Roads, and Parking Lots". Chapman & Hall, New York. ISBN 0-412-99201-9.
- [26] Jung, F. W., Kher, R. K., Phang, W. A., 1976, Subsystem for predicting flexible pavement performance, *Highway Research Record*, pp. 15-29.
- [27] Moavenzadeh, F., 1976, Stochastic model for prediction of pavement performance, *Transportation Research Record*, 575, pp. 56-73.
- [28] Alsherri, A., and George, K.P., 1988, "Reliability Model for Pavement Performance", *Journal of Transportation Engineering*, Volume 114, Number 2, pp. 294-306.
- [29] Butt, A.A., Shahin, M.Y., Carpenter, S.T. and Carnahan, J.V. 1994, "Application of Markov Process to Pavement Management Systems at Network Level," *Proceedings of the Third International Conference on Managing Pavements*, San Antonio, Texas, May, pp. 159-172.
- [30] Shahin, M. Y., Becker, J. M., 1984, Development of performance prediction models for airfield pavements, *Transportation Research Record*, Vol. 985, pp. 25-33.
- [31] Owusu-Ababio, S., 1998. Effect of neural Network Topology on Flexible Pavement Cracking Prediction, *Computer Aided Civil and Infrastructure Engineering*, Vol. 13, pp. 349-355.
- [32] Jähren, C. T., Cawley, B., Ellsworth, B., Bergerson, K. L., 1998, Review of cold in-place asphalt recycling in Iowa, *Transportation Conference Proceedings*, pp. 259-263.
- [33] Attoh-Okine, N. O., 2002, "Combining use of rough set and artificial neural networks in developed-pavement-performance modeling-a hybrid approach," *ASCE Journal of Transportation Engineering*, Vol. 128, No. 3, pp. 270-275.