Pavement Management System in Urban Roadways using Geographic Information System (GIS): A Case Study of Sari city in Mazandaran Province

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Abstract: Pavement Management System (PMS) is a set of tools that can help decision-makers to find cost effective strategies for providing, evaluating and maintaining pavement in a serviceable condition. The pavement condition index (PCI) is a simple and economical method to monitor the condition of roads' surface. Road maintenance and pavement rehabilitation are pretty costly, so the considered budget should be used wisely; otherwise it would be uneconomical. Thus, in order to have an acceptable situation in managing the foundation, management support system is needed. Nowadays, there are various systems to approach this goal. This paper denotes using Geographic Information System (GIS) in pavement management system (PMS) to reduce heavy upkeep costs and charges assigned to users considering the vast of roadways network. GIS has provided an appropriate platform to all indexes intercommunicated with PMS. As a result, a strong tool derives from PMS/GIS to improve all PMS aspects. Hence, creating and initiating of a road management system plus using capabilities of GIS in it, will highly reduce the costs of repairs and optimize the maintenance schedule. In this research, in addition to review the main concepts of PMS, some GIS capabilities has been introduced and their usage in PMS will be presented. At the end, by doing fieldwork on main streets, some failures in asphalt surface was distinguished and began creating a database which could help us monitor the urban roadways pavement condition.
[Shabannezhad N, Shemirani Motlagh AM, Roshan R. **Pavement Management System in Urban Roadways using Geographic Information System (GIS): A case study of Sari city in Mazandaran Province.** *World Rural Observ* 2019;11(3):25-32]. ISSN: 1944-6543 (Print); ISSN: 1944-6551 (Online). http://www.sciencepub.net/rural. 5. doi:10.7537/marswro110319.05.

Keywords: Pavement, Maintenance, Roadway, Repair, Failure

1. Introduction

One of the most important achievements in civil industry is highway networks. In recent years, construction, rehabilitation of road pavement's surface layers, have been encountered to lots of failures and cracks due to different failure types and various weather conditions as well as type of loads on it.

Nowadays, large amount of failure is caused by lack of safety control and weakness in pavement preservation. Therefore, pavement management system has been used as a vital solution to reduce costs of rebuilding and protecting irreversible raw materials. Actually, safety function and road management not only reduce the additional costs of instability of pavement elements, but also can solve the social concern about conservation of impermanence natural raw sources. On the other hand, large amount of traffic loads come from vehicles on the road pavement surface that turns into crucial factor in asphalt failure. In a small scale, city's passageways have been exposed to the most damages and failures in asphalt surfaces and pavements. So the need of inspecting the cause of failures and pavement management has been the most important part of transportation studies. Multiplicity of pavement failures could be easily influenced by factors such as: environmental situations, overloads and structure endurance reduction over time that could lead to monitoring and controlling the pavement's situation which is called "pavement management system".

Process of improving the PMS during the time depends on various factors. One of the most remarkable reason is to utilize new accessible technologies in collecting data. Aforementioned important reasons, will provide feasibility of comprehensive access to all traffic data with low expenditure, and also improvement in decision-making against section's failure. GIS is one of the all-purpose technologies in pavement management. In fact, it is a systematic software for collecting, accumulating, merging, displaying and evaluating information, considering environmental circumstances.

2. Description of study area

This study took place in Sari, the largest and the most populated city of Mazandaran province, located

in the northern Iran. Most of its roads maintenance and repairs have been done carelessly without doing any studies and investigations and unfortunately was taken by personal decisions. Maintenance procedure has always been done in different sections in irrelevant locations, and unfortunately, repairs were not organized. Hence, there were a lot of motivation for developing a simple systematic procedure with field inspection. Thus, in this study, survey and evaluation pavement conditions in main streets with use of geographic information system (GIS) were considered.

3. Literature Review

In the field of pavement management systems and evaluation methods, lots of projects have been done as yet. In recent decades, GIS has been widely used in U.S. transportation agencies. In April 1968, a proposal for a research project has been sent to Texas Department of transportation for further investigation, which was called "research and development of possible methods for designing roadway pavement systematically". The Proposal included background issues in pavement, summary of results obtained from studied projects of that year and presenting the possibility of using systematic analysis with the purpose of improving pavement design methods. In 1980, AASHTO and FHWA held up several workshops with the aim of "pavement management development in next 10 years".

Generally, GIS allocates to roadway networks with high traffic volume (crowded sections, city centers, high traffic highways) and rarely rural roadways with low traffic. Although, in a wide vision, high cost for this method might have influenced this decision. Technological use of GIS software has not only been used in America. As a matter of fact, more researches confirm that European countries including Ireland in 2007 and England in 2008 had also used the similar method for PMS.

In 1985, a conference was held in Toronto, Canada with the purpose of research activities in pavement management system. According to the changes and updates in pavement management perspectives, in 1987, an exclusive conference for pavement management was held up with the purpose of developing PMS networks in American states and Canada's provinces.

The results of scientific and practical conferences in 1996 led to allocate considerable funds for pavement management system which included:

- A traffic system with reliable infrastructures should be one of the most important factors in structural costs reduction in any countries.
- Assigning more than 62 million dollars in a year for physical protecting and improving usage of roads.
- Allocating more than 23 million dollars for road safety facilities.
- Completion of traffic information database systematically or by field inspection.

In 2003, in Texas university, Federal Highway Administration (FHWA) provided a pavement management system including collection of tools and methods which could forecast costs strategies which could help development and maintenance in service situation. This PMS was offered to notice the dominant situation of roads which was based on geographic information system that could manage data in table-form and put them to a database's framework.

3. PCI Determination Procedure

Pavement management system is a great tool by which, decision-makers can benefit from by acquiring strategies and effective policies for road maintenance at a well-deserved level. PMS consists of coordinated and comprehensive set of activities in the field of planning, design, construction, maintenance, assessment, improvement, reconstruction and pavement researches.

Pavement process includes:

- Pavement network definition;
- Measurement of pavement condition;
- Forecasting pavement condition;
- Management in project scale and in network scale.

The First step in this process is defining the pavement network. each network should be divided into manageable sections. This process will happen just once, and the rest will repeat periodically. How it measures and predicts, depends on whether the pavement is in a network scale or a project scale.

"project-level management" means to select the best choice for repair and maintenance in each single project. First of all, there is a detailed assessment and review for each project and then, the most practical option is chosen. In this type of managing, decision-makers generally do not concentrate on financial resources for other pavements of a network. On the other hand, the process that considers the needs of entire network sections is called "network-level management".

The PCI calculation method is expressed in different references, so there is no need to express it. If all sample units are examined in a single piece, PCI can be obtained by averaging the PCIs of all sample units. If all sample units are selected based on the systematic random method or the representative method of the selected piece, the PCI of the piece is

determined by the average of the sample units inspected (Figure 1).

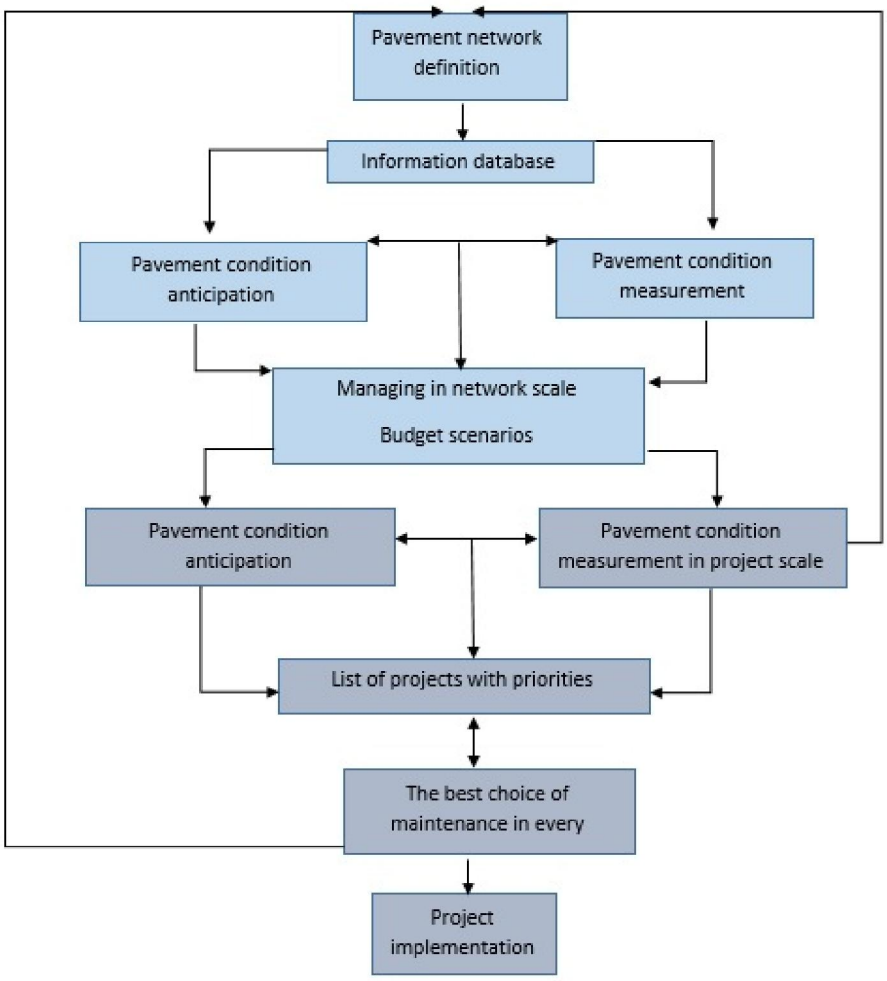

Figure 1. The process of road pavement

4. Types of pavement failures and repair methods

Pavement structural design is much more complicated than it seems in comparison to other structures in civil engineering. In designing pavements, sudden failures are not common, unless the pavement has not been executed in a right way.

Precise recognition of different types of pavement failures and their causes, will lead to proper planning for repair and maintenance at the right time. For this purpose, common types of failures in pavement will be briefly introduced (Table 1):

Table 1. Types of failures in pavement

No.	Type of failure	No.	Type of failure
1	Patching and utility cut	11	Alligator cracking
2	Polished aggregate	12	Upheaval
3	Pot holes	13	Block cracking
4	railway	14	Pat holes
5	rutting	15	Corrugation
6	Shoving	16	Depression
7	Slippage cracking	17	Edge cracking
8	delamination	18	Joint reflection cracking
9	Weathering and raveling	19	Shoulder drop-off
10	Longitudinal and transverse cracking		

Methods of repair and maintenance are categorized into three groups:

1- Positional maintenance: involves patching and filling the cracks

2- General maintenance: involves the use of sealants without stone materials and using slurry mixtures

3- Fundamental maintenance: involves coating and recycling

5. Methodology

In most resources, pavement evaluation methods are categorized into two groups:

1- Obtaining information by manpower;

2- Obtaining data by mechanized equipment and machinery.

Data collection by human is done in three ways. In the first approach, "walking survey", the expert analyzer tracks the path along the route and takes notes of the type, intensity and the extent of any failure. In the second method," windshield survey", the person slowly moves along the shoulder of the road while moving by a car and examines the condition of the pavement. Finally, in the third one, the combination of both is used.

In recent decade, due to the limitation of collecting data by human sources in case of safety, speed and influence on traffic flow, data acquisition has been expanded to using of advanced vehicles and equipment. However, the information derived from the walking survey is more accurate and more valid than the windshield survey method.

The main pillar of the pavement management system is to collect, analyze and evaluate the information. The most important aspect of developing a PMS is to collect, manage, control and analyze the pavement status data in a significantly detailed format. Due to geographic information systems have spatial analyzing capability, they can coordinate themselves with the geographic nature of road networks. Actually, they are the most suitable tool for improvement in management and controlling the pavement's status (Figure 2).

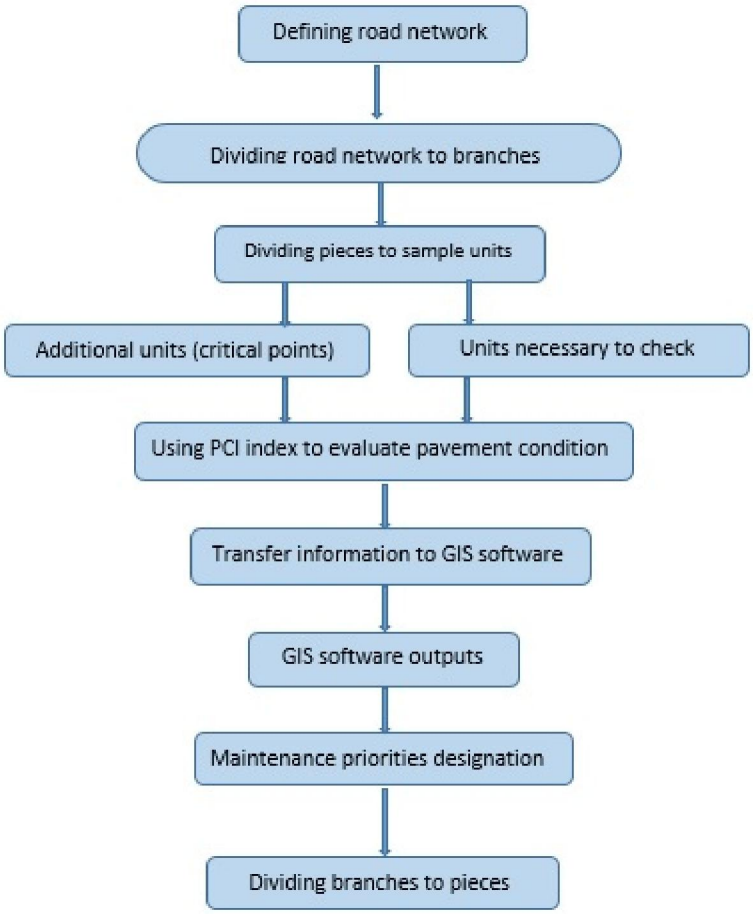

Figure 2. Pavement maintenance procedure

The method used in this essay to classify the malfunctioning the pavement, is the same as PCI proposed by U.S Military. PCI index for developing countries like Iran, is the most appropriate method at this time. PCI is a numerical index which is variable between 0 for unusable pavement up to 100 for ideal pavement. PCI calculation is based on a visual inspection that indicates failure's type, severity and scale.

PCI was originally proposed as an indication of structural integrity of the pavement and its operational status. Information derived from inspections is taken as part of a pavement status check, providing an internal cognition of failure's causes and their relation with loading or atmospheric conditions. Failure rate is a function of type, severity, scale and density of the failure. Since there are many different possible situations, obtaining an index which contains all aspects is very difficult. To solve this problem, indexes entitled to "decreasing coefficients", were offered. Actually, they are weighting variables that show the impact of every single factors of type, severity and density on pavement status.

The failure severity levels and related decreasing indexes have been found on precious experiences by engineers, field experiments, instructions evaluation and accurate definition of various failures; so it is possible to determine a compound sign of PCI failure.

First step to implement PMS is to detect and to define the road network. At the beginning, a vital decision is needed to found which sections can be considered as an independent section with the purpose of storing them in software environment in a single database; so that much more efficient performance is expected in data entry and exporting reports.

In the next step, networks must be divided to "branches" and "pieces". Branch is referred a part of network that can be easily identified; like a street. Branch by itself can be divided to several pieces. Pieces can be classified based on their geographic situation in the network or any other variable.

6-1. Defining the branches

Selected trails are the main roads and streets without taking alleys into account. A map of the traffic design was received in accordance with the aerial photos of Sari by consulting with the authorities of the municipality. The map included all the complications, including access passages and a comprehensive plan of land allocation (Figure 3).

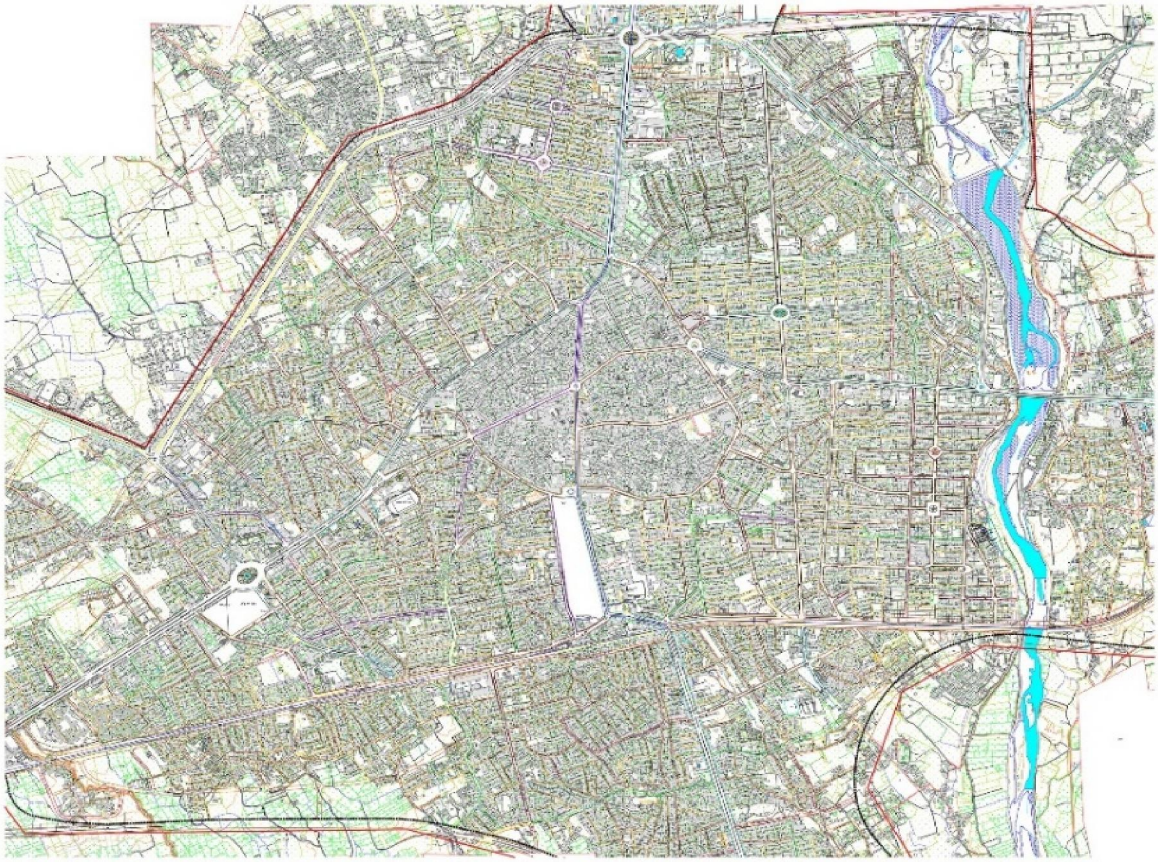

Figure 3. Comprehensive traffic design map of Sari city

By summarizing this map, under AutoCAD software platform, the range of main passageways of the pavement network was determined (Figure 4, Figure 5).

Figure 4. Main streets map of Sari city

Figure 5. Dividing pavement sections to sample units

In order to better assessment of the situation, the main streets were considered as a branch in the pavement network. Based on type of traffic flow and the traffic behavior changes in different areas of origin and destination, important traffic nodes in the area were considered and were spliced into pieces. (Figure 5)

6-2. Dividing branches to sections and sample units

Part of the pavement to be examined is a unit of specimen. In unprocessed pavements or asphalted pavements, a unit is defined as a 230-meter surface with a 90-meter tolerance. Particular attention is paid to the division of the pavement into sample units. To obtain the indication of the status of the pavement PCI, it is not necessary for all sample units to have the same dimensions equal to each other, but they should conform to the recommended dimensions for the sample units. Therefore, parts were divided into sample units at 30 meters' intervals.

6-3. Detecting sample units for investigate

Inspecting all sample units in a pavement may require considerable effort. Especially in large pieces. To limit the amount of resources used for inspections, it should be planned in such a way as to accurately estimate the position of the pavement by inspecting only a few sample units in a given section.

Network-level investigation can be accomplished by examining a limited number of sample units per segment. But in order to set up work plans and contracts, project-level management needs precise data, so more sample units need to be checked in comparison with network-level management.

6-4. Selecting sample units

Selected sample units should represent the whole position of the piece. The main purpose of budget estimation and network evaluation is to obtain a logical rating with minimal cost. One of the major drawbacks in sampling is that sample units that are undoubtedly in a bad condition, may not necessarily be subjected to review, whereas, on the contrary, sample units that may have rough breakdowns (such as failure Railways Railways) may be considered inappropriately as a sample unit. To avoid these bugs, unusual sample units must be identified and checked as "additional sample unit" instead of being representative of the sample unit. When additional sample units are checked, some pieces of the PCI token are changed to avoid extrapolation of unusual situations throughout the unit.

6-5. Run a status check

There are different methods for conducting a status check in order to determine the PCI based on the type of pavement procedure used for inspection. For all types of procedures, first, the pavement should be divided into sample units and, be selected as previously described. To evaluate the pavement status in an asphalt pavement, inspectors need a manual metric, as well as a bevel and a ruler to measure the depth of grooves or nicks, as well as a PCI manual for measuring the length and area of the crash.

Conclusion

Alternate assessments on current pavements indicate the status of pavements. Due to the performance characteristics of the PCI, pavements with lower PCIs were selected for maintenance operations. In pathways management, at the network-level, various existing projects are prioritized according to the budget considered to each project for maintenance operations, due to budget constraint. In this study, the need to create and operate a Pavement Management System at all levels, has been specified. The necessity of creating a database and specifications of the database structure and the necessary information components for managing the pavement were introduced. The introduced system will be a complete backup system for decision-making and management in the direction of pavement maintenance. By having precise data and accurate reports, repair and maintenance costs will be optimized. This system gives the authorities a comprehensive overview of the status of the city's inner passages. With the implementation of this system, the accuracy and speed of decision-making will increase and traditional methods of field-based decision-making will be eliminated.

References:

1. Dicleli M, Bruneau M. Seismic performance of single-span simply supported and continuous slab-on-girder steel highway bridges. Journal of Structural Engineering, ASCE; 121(10): 1497-1506, 1995.
2. AASHTO. LRFD bridge design specifications (4th ed.). Washington (DC): American Association of State Highway and Transportation Officials; 2007.
3. Chopra AK. Dynamics of structures: Theory and applications to earthquake engineering (2nd ed.), Prentice Hall, Englewood Cliffs, 2001.
4. Computers and Structures, Inc. SAP2000, version 7.4, Integrated structural analysis and design software. Berkeley, CA; 2000.
5. Prof. Dr Fareed M.A. Karim, Dr Khaled Abdul haleem Rubasi, and Dr Ali Abdo Saleh. The Road Pavement Condition Index (PCI) Evaluation and Maintenance: A Case Study of Yemen.

6. Pavement Management System for the cities of Avenal, Hanford, Lemoore, and county of kings. Proposal by Funtain valley Office; 2018.
7. Meng L, Yuan J. and Wenial C. (2012). "Application of GIS in Shanghai Airport Pavement Management System". Shanghai Airport Authority, Shanghai 200335, P.R China.
8. UK Roads Liaison Group (2011). Well-maintained Highways, Code of Practice for Highway Maintenance Management. Department for Transport, The Stationery Office, London.
9. Adeyinka, olumide Adedamola, "Development of a Prototype Pavement Management System for Municipal maintained Roads and the Integration with a Geographic Information System" (1992).
10. Shahin, M.Y. pavement management for Airports, Roads, and parking lots, 2nd ed.; Springer Publishing Company: New York, NY, USA, 2005.
11. ASTM. ASTM D6433-18, Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys; ASTM International: West Conshohocken, PA, USA, 2018.
12. WSDOT (1999). "Washington State Highway Pavements: Trend Conditions and Strategic Plan". WSDOT Field Operation Service Center, Materials Laboratory. Olympia, USA.
13. Flintsch, G.W.; Dymond, R.; Collura, J. Pavement Management Applications using geographic Information systems; National Academics Press: Washington, DC, USA, 2004; Synthesis 355.

8/7/2019