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Development of GIS Integrated Pavement Management System (PMS) for Rural Roads

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Abstract:
Pavement Management System (PMS) is a set of tools or methods that can assist decision makers in finding cost effective strategies for providing, evaluating, and maintaining pavement in a serviceable condition. This study aim to how ArcGIS software is used as a decision support tool for the maintenance of road networks; the paved rural road stretches of kottayam district is taken as a study area. Pavement Surface Evaluation and Rating was performed on each road in the network using pavement condition rating form and scale. Spatial and a Visual spatial information of the road network which include the digital map of the road network, the coordinates of defect's location, defect type, image and size etc. were used to develop a relational database. The database developed in EXCEL software was imported into Arc GIS software to allow for ease of analysis and query of the database and ease of visual and graphical displays of results. The main objective of this study is to develop a GIS based pavement management system that provides information for use in identification of more deteriorated road, optimum maintenance strategy and also pavement condition for future scenario. In this study, a pavement condition model is also developed based on GIS Database. Statistical software SPSS is used for this purpose.

Keywords: Pavement Management System, Pavement Condition Rating, Arc GIS, SPSS

1. INTRODUCTION

The road networks are capacity constraint and structurally deficient due to lack of timely maintenance, rehabilitation and upgradation. This has adversely affected the traffic movement, resulting into higher operating costs and delays. Maintenance and up gradation of such a large network is a challenging task because of the logistics and constraints of resources. There is a need to manage the network more efficiently in a scientific manner; the most important aspect lacking is the application of information system. A variety of spatially integrated data are important to pavement management decision making. GIS technology is shown to be the most logical way of relating these diverse, but relevant, data. The GIS based pavement management system would eventually lead to the development of the frame work for GIS based Pavement Management System). Here I had reviewed the role of GIS for pavement management system.
The Pavement Management Systems is 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. It provides the information necessary to make these decisions. The PMMS consists of two basic components: A comprehensive database, which contains current and historical information on pavement condition, pavement structure, and traffic. The second component is a set of tools that allows us to determine existing and future pavement conditions, predict financial needs, and identify and prioritize pavement projects.

2. NEED FOR THE STUDY

The Road User Cost Study in India has established that due to improper maintenance and poor surface condition of road pavements, there is a considerable economic loss to the country due to increase in vehicle operation costs. If the road pavements are maintained to the desired level at an appropriate time, it is possible to save the losses in road user cost. In view of the budgetary constraints and the need for judicious spending of available resources, the maintenance planning and budgeting are required to be done based on scientific methods. The whole life cycle cost analysis based on the road user cost relationships enables the decision makers to examine financial and economic implications of various options for formulating appropriate strategies for cost effective use of resources.

3. OBJECTIVES OF THE STUDY

- To detect and locate distresses in selected road surface.
- Map out and digitize the road network of the selected study stretch.
- To classify the type, severity and quantity of the distress along road stretches.
- Evaluate the condition of the road pavement.
- Identify the appropriate maintenance and rehabilitation project needs on the roads.
- Develop a GIS database of the spatial and attribute data of the road network.
- Developing Model for pavement condition prediction.

4. LITERATURE REVIEW

Geographic information systems (GIS) are much more than computer generated maps. GIS is a sophisticated database management system designed especially for spatially referenced data. The use of Geographic Information System (GIS) in pavement management is utilized at different levels and covers the different steps from developing to implementing a pavement management system. GIS is used in the design of the PMS database, in the data integration process (inventory, history, condition, etc) and finally in communicating the results of the PMS (Smadi, 2004). Karwan Ghazi Fendia (2013): This study aim to produce a GIS Database for Road Surface Monitoring. This system is easy to use, cost-effective, deployable, and can be used effectively by local authorities. The study consists of producing a GIS database for road surface monitoring from collected distress data. The information about the road distresses are collected in Nottingham city – UK. However, this study didn't consider the traffic volume is an account for pavement distress. NOR A. M. Nasir et. al (2016): In this study , a road distress data was collected using GPS applications supported by Supersurv 3 software. The study shows that the GIS method helps to produce a good spatial database. The objective of this paper is to identify the locations of road distress in UKM. The coordinates of the location in distress will be marked using GPS technology. The second objective is to produce spatial data storage of road distresses by using GIS, and the last objective is to classify the road distresses into three severity levels and to study the relationship between the road distress and the slope factor. This study didn't make a pavement prediction model and pavement condition model. Vishwanath G, Mahdev, M. R. Archana, and Krishna Prapoorna Biligiri (2013) have done the development of pavement management strategies for arterial roads. This study aims at bringing out the methodology used in carrying out the survey on the pavement and for rating of the pavement (PCI) with the case studies of four arterial roads of Rajarajeshwari Zone, Bangalore city and the PCIs of rating of these pavements at the time of studies was found to be from very poor to excellent. Pavement management strategies have been proposed based on the condition rating. There are several studies conducted that describe, how GIS technology can help in visualizing and interpretation of the data for decision making purposes in the field of road maintenance and rehabilitation. Very few studies were conducted related to pavement management with GIS in a rural roads containing considerable amount of traffic.

5. METHODOLOGY

5.1 . Project Study Stretch

The project study stretch chosen for this research include 7 rural road segments in kottayam district. The details of road stretches shown in the following table 5.1.

Table 5.1. Showing the details of study stretches

No	Road Name	Length in Km	Pavement Type	Divided carriage way	Width in m	No. of Sections
1	Nedumavu-Udhikkuzha Road	1.3	Flexible	No	3.8	13
2	Nedumavu-Mukkali Road	1.3	Flexible	No	3.8	13
3	Kooropada-Oravakkal Road	1.9	Flexible	No	4.2	19
4	Ambalappady-Madappadu Road	0.8	Flexible	No	3.75	8
5	Chennamattom-Panappally Road	0.9	Flexible	No	4	9
6	Pinnakkanadu-Chettuthodu Road	2.1	Flexible	No	4	21
7	Kappadu-Manthara Road	1.5	Flexible	No	3.8	15

5.2 Data Collection

Pavement Surface Evaluation and Rating was performed on each of the roads using pavement condition rating form and pavement condition rating scale. A visual conditional survey was conducted by walking through the road lengths. Data collected during the exercise include:

- Selected road stretches within the district are visited by vehicle and data about the type, severity level, geographic location, dimensions, and photos of the distress are recorded.
- A hand-held GPS can be used for the location of distresses.
- High resolution digital camera used for capturing images of distresses.
- Dimension of each distress is measured by tape at each severity level.

5.3 Traffic Volume Survey

Traffic volume survey conducted on selected road stretches at peak hour. The above study stretches is also considered for traffic volume survey.

5.4 Geotagging

The geographical identification metadata, such as latitude and longitude, is added to every photo taken for each point. Arc GIS software 10.3 in conjunction with the GPS data is used for geotagging.

5.5 Data Processing and Analysis

The collected data which includes the defect type, defect location, extent etc., were input into EXCEL, processed as appropriate and imported into ArcGIS Software for establishing database. The flow chart of the data processing is shown below in fig 5.1.

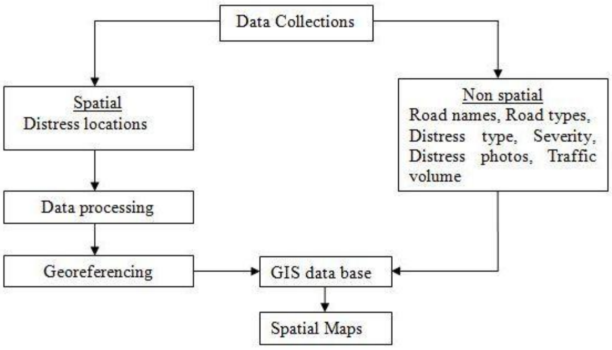

Figure. 5.1: Showing data processing steps

5.6 Establishing Database for GIS

After creating attributes table of all study stretches, different details related to pavement like distress type, images of distress, severity, quantity of distresses along road stretch and traffic volume are assigned to each road stretch. Microsoft excel software is used for this application.

5.7 Developing Pavement Condition model

In this study, pavement condition model were developed in SPSS software. The pavement distresses and traffic volume data collected over 7 road segment including 98 uniform stretches of 100 m length covering rural roads have been used for modelling. Data on the randomly selected 5 road segment (approximately 70% of the observed values) were used for model development, and the remaining 2 road segments (30% of the observed values) were kept aside for the model validation. A multiple linear regression model has been developed to find the relation between PCI (Pavement Condition Rating) and pavement distress parameters using SPSS software (www.spss.com). In this model, PCI value is taken as the dependent variable and the measured distress quantity, severity, pavement condition score and traffic volume as independent variables.

6. ROAD PAVEMENT CONDITION IN A GIS DATABASE

For the preparation of database of pavement condition in ArcGIS the following steps followed.

1) Collection of pavement distress details (image, type, severity, quantity and location).
2) Traffic volume at peakhour along all road stretch.
3) Digitization of road network map of kottayam district collected from kerala PWD.
4) Pavement condition data input into EXCEL and imported into ArcGIS.
5) Geotagging of distress photos with location and details.
6) Developing GIS database with pavement condition details and images.

The following figure 6.1 showing GIS mapping of distresses in Pinnakkanadu – Chettuthodu Road.

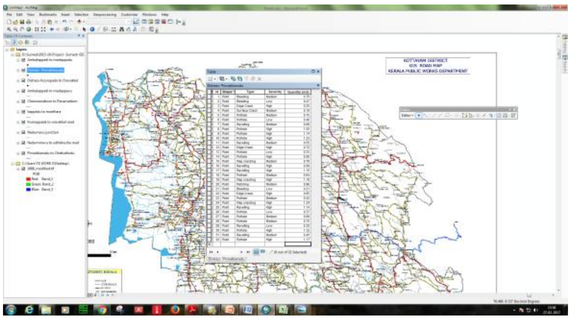

Figure .6.1. Showing GIS mapping of distress in Pinnakkanadu - Chettuthodu Road

7. PAVEMENT CONDITION MODEL

The distress parameters such as cracking, potholes, rutting, ravelling and patching directly affect the condition of the pavement, the impact of this distress in terms of extent and severity and also consider the traffic volume at peak hour which needs to be considered to develop a model which would be relevant in rural roads in Indian context. This would also help the decision makers to identify the optimum strategy for maintenance before the repair costs become too high. In addition, measuring the condition and performance of roads are continuously developed overtime with the new methods and improvements.

7.1 Developing pavement condition model

In this study, the pavement distress collected in the terms of extent and severity is converted to numerical value and for appearance of each distresses put the score from 0 to 3 (KYTC Pavement Distress Identification Manual 2009). There are a total of 4 input variables, such as extent, severity, appearance and traffic volume.

Model in the form of PCI= aX1+bX2+cX3+dX4, (1)
PCI = Pavement Condition Index (Dependent variable)
X1 = Extent of distress in square metre
X2 = Severity of distress (Score 0 to 9)
X3 = Traffic volume in PCU
X4 = Appearance of distress (Score 0 to 3)
a,b,c and d are the coefficients of independent variables

7.2 Estimation of PCI value

PCI is a numerical rating of the pavement condition that ranges from 0 -100 with 0 being worst possible condition 100 being the best possible condition (ASTM D 6433-07). The PCI provides a measure of the present condition of the pavement based on the distress observed on the surface of the pavement, which also indicates the structural integrity and surface operational condition. The PCI values obtained from visual inspection i.e. distress survey by recording the severity and extent of the various distress namely cracking, rutting and potholes occurred to pavement can be utilized well in prioritizing the maintenance strategies. The following calculation procedure is adopted for PCI value estimation (Vishwanath G et.al , 2013). PCI value estimated from deduct value (DV), which is defined as the value that represents the amount of distress that a pavement has undergone or is subjected to. The density of each distress was calculated using the Eqn 2.

$$\text{Density} = \frac{\text{Distress amount in square meters}}{\text{Sample area in square meters}} \times 100\% \qquad (2)$$

The DVs were determined from the DV curves, then for each distress type and severity Total Deduct Value (TDV) was computed by summing up all the DVs then the Corrected Deduct Value (CDV) was determined from CDV curve shown in Fig. 7.1. Then the PCI was computed using the Eqn. 3

PCI = 100 – CDV (3)

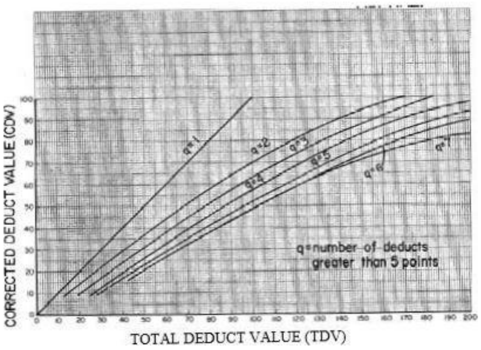

Figure.2. Deduct value curves for asphalt-surfaced pavements

Determination of appropriate maintenance measures for various ranges of PCI value is shown in table 7.1.

Table.7.1:Determination of appropriate maintenance measures

PCI Range	Rating	Maintenance Measures
86-100	Excellent	No maintenance required
71-85	Very Good	Little or no maintenance
56-70	Good	Routine maintenance, crack sealing and minor patching
41-55	Fairs	Preservative treatments (seal coating or thin non-structural overlay 2" or more)
26-40	Poor	Needs patching and repair prior to major overlay Milling and removal of deterioration extends the life of overlay.
11-25	Very Poor	Needs reconstruction with extensive base repair.
0-10	Failed	Total Reconstruction

8. DATA ANALYSIS AND RESULTS

8.1 Pavement distress analysis and Estimation of PCI

Pavement distress analysis result and obtained PCI value for each stretch is shown in table 8.1.

Table 8.1: Pavement distress analysis result and PCI

Road Stretch	PCI	Extent	Severity	Traffic (PCU)	Appearance
Kooropada to Oravakkal	46	0.88	3.81	256	1.6
Kappadu to Manthara	16	0.71	4.7	151	2.9
Pinnakanadu to Chettuthodu	22	0.75	4.69	189	2.6
Nedumavu to Udhikkuzha	51	0.89	3.47	135	2.4
Nedumavu to Mukkali	40	0.67	5.43	77	2.2
Ambalappadi to Madappadu	59	0.66	5.25	74	2.3
Chennamattom to Panamattom	72	0.8	4.36	130	1.8

8.2 Model Output

The final model that is obtained from SPSS analysis is shown in table 8.2.

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Extent	131.809	2.808	2.755	46.934	0.014
Severity	2.007	0.399	0.239	5.023	0.125
Traffic	-0.172	0.007	-0.788	-23.987	0.027
Appearance	-20.889	0.798	-1.324	-26.167	0.024

So, the model is,

PCI= 131.809X1+2.007X2-0.172X3-20.889X4

8.3 Model Validation

The validation process can involve analyzing the goodness of fit of the regression, analyzing whether the regression residuals are random, and checking whether the models perspective performance deteriorates substantially when applied to data that were not used in model estimation. Thirty percentage of the data that is not used for calibration is used for validating the models. The model was validated using student t -test. A plot has been drawn between estimated and observed PCI value as shown in figure 8.1. The scatter of the points about the line is an indication of the effectiveness of the model developed for estimating the PCI.

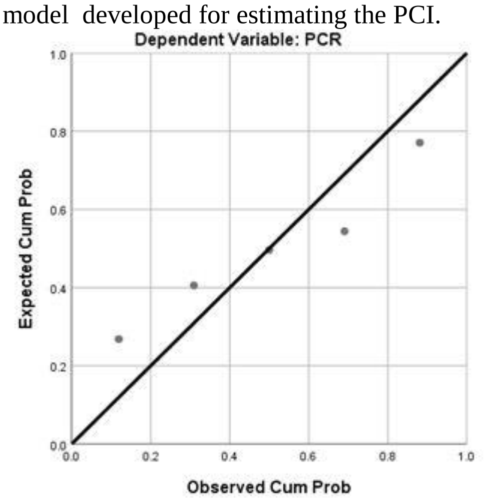

Figure .8.1. Plot between estimated and observed PCI value

The validation result obtained from SPSS output is shown table 8.3.

Table. 8.3: Model validation result from SPSS

Parameters	Mean Difference	Student-t	95% Confidence interval for difference	
			Lower Bound	Upper Bound
Extent	0.73	10.429	-0.1594	1.6194
Severity	4.805	10.798	-0.84926	10.45926
Traffic	102	3.643	-253.77	457.77
Appearance	2.05	8.2	-1.12655	5.22655

The above results show that all mean difference value fall under the 95% confidence interval value. So the model is validated.

8.4 Pavement condition in GIS database

The following figure 8.2 shows that one of the GIS database of pavement condition for Pinnakkanadu- Chettuthodu Road. The corresponding pavement distress image is geotagged as a raster in GIS database.

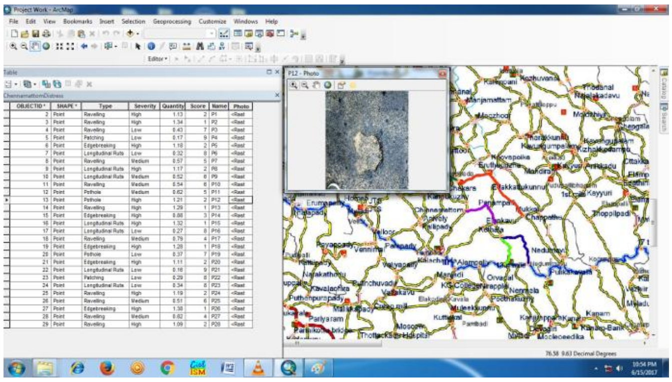

Figure .8.2. Showing pavement condition in GIS database

9. DISCUSSION AND CONCLUSION

- It was observed from the analysis of pavement distress data in GIS database that the road stretch Pinnakkanadu to Chettuthodu and Kappadu to Manthara road needs reconstruction with extensive base repair. It is due to considerable amount of daily traffic with least structural adequacy.
- A quick and cost-effective method is proposed in this work to establish a database for GIS for road surface monitoring purposes.
- The model developed in this study depicting the relationship between the PCI and the pavement condition parameters shows that besides the usual distresses the traffic volume is not significantly affect the pavement condition in the case of rural roads in Indian contest.
- Validation of the model was carried out using Student-t test and the model gave good result and the model can be useful for estimating PCI value for rural roads considering the distress parameters and traffic volume.

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