Performance Assessment and Pavement Management of Urban Roads Using GIS in Bangalore City

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Abstract

Geographical Information System (GIS), Remote Sensing and Global Positioning System (GPS) are well suited for Highway Maintenance and Management studies. Government of India has been investing huge amounts on road connectivity. Flexible Pavements form considerable part of the Highway's in India because of the low construction cost involved. Pavement Maintenance and Management System (PMMS) make use of the deterioration models to predict pavement condition at a future data, based on which the maintenance strategy can be formulated.
This study is an effort to model the performance of urban roads using Geographical Information System (GIS). Detailed data collected including rutting, potholes and cracking. The database is inputed into GIS software which shows the information of all the attributes related to the road and it will be used for decision making and problem solving.

1. Introduction

Road Transportation occupies a very dominant position in the overall transportation system of India. The growth of road traffic in the post independence era has been quite unprecedented both in terms of goods and passenger traffic. Unfortunately, the corresponding growth in the road network has not been commensurate with the huge growth in vehicular population. The traffic loadings have also been much heavier than the specified limit of 10.2 tonnes. Without adequate and timely maintenance, roads deteriorate excessively, leading to higher vehicle operating costs, increased number of accidents and reduced reliability of transport services.

Pavement management system can work effectively only when they are constructed by organically combining all activities concerned with road pavement (planning, design, construction, maintenance, rehabilitation, evaluation, economic analysis, and research) and the data bank. Then, the most important items are the establishment of a serviceability index which represents pavement quality, and a prediction of performance, which is represented by the relation between time (and/or traffic) and the index. Pavement quality consists of two primary factors: riding quality and skid resistance. The factors influencing riding quality are pavement distress and/or roughness. Three major factors of pavement distress are cracking, rutting, and longitudinal profile. Recommendations are usually based on preventive maintenance, rather than allowing a road to deteriorate until it needs more extensive reconstruction.

Typical tasks performed by pavement management systems include:

1. Inventory of pavement conditions, identifying good, fair and poor pavements.
2. Assign importance ratings for road segments, based on traffic volumes, road functional class, and community demand.
3. Schedule maintenance of good roads to keep them in good condition.
4. Schedule repairs of poor and fair pavements as remaining available funding allows.

Development of computerized pavement-management systems and knowledge-based expert system decision tools to assist engineers in the planning, design, and evaluation of effective maintenance and rehabilitation strategies. However, regardless of whether such strategies, and associated investment decisions, are derived by expert-system approaches or by human experts, the same pavement-surface-condition data are required as basic inputs. In the case of bituminous pavements, this includes the extent and severity of such distresses as fatigue (or alligator) cracking, longitudinal cracking, transverse cracking, ravelling, and patching among others. These data are indicators of structural and functional performance.

There is a need of developing a scientific approach towards determining the maintenance and rehabilitation requirements of pavements. Efforts are also needed to develop road management and planning tools to improve upon the existing road network. These tools are essential for assessing the financial needs, evaluating the alternative maintenance strategies and prioritizing the work programs. In such a situation, development and practice of an efficient Pavement Management System (PMS) would provide objective information and useful analysis to ensure consistent, and cost-effective decisions related to preservation of the road networks.

A pavement management system (PMS) is a valuable tool and one of the critical elements of the highway transportation infrastructure. The earliest PMS concept can be traced back to the 1960s (given by **Norlela Ismail et.al.[6]** and **Amir Tavakoli et.al.[7]**). With rapid increase of advanced information technology, many investigators have successfully integrated the Geographic Information System (GIS) into PMS for storing, retrieving, analyzing, and reporting information needed to support pavement-related decision making. The main characteristic of a GIS system is that it links data/information to its geographical location (e.g., latitude/ longitude or state plane coordinates) instead of the milepost or reference-point system traditionally used in transportation. Moreover, the GIS can describe and analyze the topological relationship of the real world using the topological data structure and model. GIS technology is also capable of rapidly retrieving data from a database and can automatically generate customized maps to meet specific needs such as identifying maintenance locations.

Geographic information systems (GIS) represent an information technology composed of hardware, software, and data used to gather, store, edit, display, and analyze geographic information. Recent advances in the ability to collect accurate locational information where GIS is brought into the mainstream of development activity associated with database management and integration with the applications environment.

For the present study an Arterial Ring Road in Bangalore City is considered for the performance assessment and pavement management of urban roads using Geographical Information System (GIS) to predict the pavement performance and behaviour in near future where road survey hast to be carried out in order to study the structural and functional condition of the pavement. Then required data is collected and uploaded to the GIS software where map is digitised containing road stretches which taken for the study.

1.1. Objectives of Present study

1. The main aim of the present study is, for the evaluation of pavement performance of selected stretches of Bangalore city roads.
2. Constructing GIS based data for urban roads by considering both structural and functional condition data.
3. Prediction of future pavement condition under different maintenance strategies.

1.2. Scope of Present study

1. To evaluate functional condition of Pavement Inventory of Surface Distress such as Cracking, Patching, Rutting, Ravelling and Potholes along with Pavement Unevenness/Roughness survey by Bump Integrator.
2. Structural evaluation of pavement by carrying out Benkelman Beam Deflection study.
3. Uploading the pavement performance data to the GIS software in the form of DBMS (Data Base Management System).

2. Literature Review

Toshihiko Fukuhara et.al.[1] : It provides a system that uses laser, video, and image processing techniques was developed. This system consists of a survey vehicle and a data-processing system. The survey vehicle can measure cracking, rutting and longitudinal profile simultaneously, without contact, rapidly and accurately. The data-processing system can convert the measured data automatically into formats that can be used in the pavement data bank. The system allows automatic crack recognition that has conventionally but only performed by humans.

Measurement and data processing of cracking, rutting and longitudinal profile have been completely automated and improved the working efficiency remarkably and also having a unique line finding algorithm. Where a special multi-microprocessor system being developed, enabling automatic crack recognition and the problem in data-analysis being solved.

Turki I et.al.[2] : Change in surface roughness was considered a measure of pavement surface deterioration. Regression models were developed to examine the effects of routine-maintenance expenditure level, pavement age and traffic loading in surface roughness.

Six routine maintenance activities were initially considered in this research: shallow patching, deep patching, remix levelling, seal coating, sealing longitudinal cracks and joints. In the Intern Guide (AASHTO 1981), pavement deterioration was represented by serviceability loss, or PSI loss. In this study, through knowing pavement surface roughness before and after applying different levels of routine maintenance on a given section of a highway, pavement surface deterioration was measured as a change in surface roughness. This concept is used in this paper to reflect the effectiveness of routine in reducing pavement surface deterioration.

They concluded that both pavement age and traffic loading variables were significant. So these models were employed to evaluate the effects of pavement age and traffic loading on change in surface roughness and consequently on maintenance effectiveness. Routine maintenance effectiveness for pavements in fair or good condition was found to be higher than that for pavements in very good condition. The maintenance work involving premix levelling and seal coating was found to provide a relatively higher effectiveness than the work involving joint and crack sealing and patching.

Mohd Zulkifli B et.al.(3) : In this study, the author has adopted GIS application software – ArcView, and has reviewed and analyzed its effectiveness in managing road database. These data are then used to assist the management to ensure effective and systematic road maintenance. A typical model of roads in Penang, Malaysia is used as a case study.

The adoption of GIS will lead to a more organized management of digital data especially those related to road data. Particularly, this system application also increases work productivity in managing road maintenance. It had capability for a fast data recall with relative ease of use, it minimizes wasteful duplication of effort in the collection of geospatial information, and it can improve data currency, accuracy and consistency of data maintained.

Stephen G. Ritchie(4) : This paper provides digital image-processing concepts and applications in pavement management, which includes pavement-surface-distress data of concern, basic machine-vision and digital-image-processing concepts, video system characteristics for automated distress-data collection.

It concluded that in a relatively short time substantial progress has been made in the development of automated systems for distress-data acquisition and interpretation, and enhanced capabilities to be expected in the near future, where digital imaging technology is playing a significant role in these efforts.

3. Functional Pavement Distress and its Concepts

Pavement serviceability-performance concept analysis information is needed on the history of riding quality of the pavement section for the time period and traffic during that time. This is to be determined by periodic observations or measurements of riding quality with records of traffic history and time. A pavement was considered to be either satisfactory or un-satisfactory. The type and extent of maintenance for a road also depends on the serviceability standard laid down, the maintenance needs, funds available and the priorities for the maintenance operations. The current engineering practice for design and construction of pavement overlays and selection of maintenance and rehabilitation alternatives is based on subjective judgment and engineering experience. An efficient pavement maintenance program is a program that identifies what maintenance action is to be taken and where and when is to be applied, so that most cost effective results are obtained.

3.1. Causes and Consequence Effects of Pavement Distress

The causes for structural and functional distresses may be of three criteria:

1. Overload including excessive gross loads, high repetition of loads and high tyre pressures can cause either structural or functional failure.
2. The climatic and the environmental conditions may cause surface irregularities and structural weakness develops**.** Example: Frost heaving, change of volume of soil due to wet and dry process, the breakup of surface resulting from freezing and thawing action or improper drainage may be the prime cause of pavement distress.
3. The cause may be disintegration of the paving materials, due to freezing and thawing and/or wetting and drying process. Example: Use of nondurable aggregates, the base-course materials may breakdown, thus generating fines which may cause unstable mix. Sub grades are also susceptible to climatic conditions.

At times construction practices may induce some effect as well the inadequate inspection during construction are certain factors that causes pavement deterioration. Design procedures must be strictly applied and field control to provide adequate pavement structure.

3.2. Asphalt Pavement Distress

Distress surveys are required for the periodic evaluation of pavements. The surveys are directed towards assessing the maintenance measures needed to prevent accelerated distress and to determine the type of rehabilitation measures needed. These surveys provide the information required to define the distress types, severity and density of identified distresses. In addition, the surveys provide the data needed to develop the deduct values associated with each distress and severity levels. The following section describes some of the pavement distress parameters viz., cracking, patching, raveling, rutting and potholes along with their probable causes. There are four

major categories of common asphalt pavement surface distress:
(1) Surface defects:
Ravelling, Flushing, Polishing.
(2) Surface deformation:
Rutting, Distortion - Rippling and Shoving, Settling, Frost heave.
(3) Cracks:
Transverse, Reflection, Slippage, Longitudinal, Block, and Alligator Cracks.
(4) Patches and Potholes

4. Data collection

In this study, from Hosur Road Silkboard junction to Nayandahally is taken, as shown in the table. Data has been collected for the following survey carried out: Volume Count Survey (VCS), Benkelman Beam Deflection Studies (BBD), Pavement Condition Survey (PCS) (By using *Hawkeye 2000*), Roughness (Bump Integrator) and digitising the stretches of the Bangalore map using GIS software.

Road Code : **SB-NDH**
Name of Stretch : Hosur Road Junction Silk Board to Nayandanahally
Category of road : Arterial/ORR
Length in Kms : 11.7
Width in Mts. : 10
No. of Lanes : 4
Shoulder/Footpath : Footpath
Drain : open drain
Median Width in Mts. : 1.5
Latitude and Longitude : 77.62287, 12.91830

Where, VOT = Volume of Traffic in PCU/hr.
PCI = Pavement Condition Index
BBD = Benkelman Beam Deflection
Roughness in mm/km.
Avg. Rutting in mm.
Temperature in degree.
Rainfall variations in mm.

5. Methodology

The methods implemented for the collection of field data is invariably wide in its application. The deflections, roughness of the pavement surface are measured by various modes. The measure of distress can be either subjective or objective. The subjective measurement may be a rating of high, medium, or low based on visual inspection. Objective measurements, are generally expensive to obtain, it is the use of different types of automated distress detection equipment i.e. pavement condition rating van for condition surveys.

Table 4.1. Pavement Distress Data Collected

Cycle	**1**	**2**	**3**	**4**
Date	**Feb 2011**	**Sep 2011**	**Dec 2011**	**Apr 2012**
VOT, PCU/hr.	1785	1885	1874	1950
PCI	70.8	67.53	63.89	14.29
BBD	0.7	0.82	0.86	0.9
Roughness, mm/km	2237	2427	2590	2893
Rutting, mm	2.5	2.9	10	10.8
Rainfall, mm	44.1	111.1	7.2	13.4

In general the instruments used for measuring roughness can be divided into two groups as follows:
(1) Systems which measure or sample the road profile from a static base. These are represented by rod and level techniques, the DIPSTICK, MERLIN and the TRRL Roughness Calibration Beam.
(2) Systems that measure the road profile over a moving datum. This group includes all dynamic profilometric systems including the TRRL Towed fifth wheel Bump Integrator and the NAASRA roughness meter.

5.1. Merlin

Merlin is acronym for (Machine for Evaluating Roughness using Low Cost Instrumentation). The machine was developed by the TRRL (given by **M A Cundill**[(5)]). The Merlin is a simple, low cost and easy to use the instrument for measuring road roughness. The instrument is given in a figure 3.1.It consists of metal frame 1.8 meters long with a wheel at the front and metal foot at the rear. Midway between the two wheels is probe which is attached to a weighted arm to hold it onto the surface. At the other end of the arm a pointer moves over a prepared chart consisting of series of columns, each 5mm wide. The device measures the vertical height difference between the road surface under the probe and the centre point of an imaginary line joining the two points in contact with the road surface. A movement of 1 mm of the probe moves the pointer 1 cm. During operation the MERLIN is brought to rest at intervals equal to one circumference of the wheel and at each consecutive location the position of the pointer is recorded on the chart.

5.2. Calibration of Bump Integrator

Before the use of Bump Integrator to measure the unevenness value of pavement surface it is essential to calibrate Bump Integrator. As the bump readings are affected by several factors such as viscosity of fluid in the damping unit, slowness in the integrator unit, tyre pressure or even the condition of the towing wheel, speed etc. it is there by necessary to calibrate the Bump Integrator unit using an equipment whose values are not affected by these parameters. The equipment Merlin is used to calibrate Bump Integrator.

5.3. Unevenness Measurements

In the present study, the evaluation of roughness for the selected stretch to describe the riding quality of the surface is measured in terms of Unevenness Index (UI) by Bump Integrator (BI).

The Bump Integrator is a response type road roughness measuring equipment. It is a single-wheel trailer unit hauled by a tractor unit or a suitable vehicle at the specified uniform speed of 30 kmph by a towing vehicle. The vertical oscillations of the BI are integrated with the help of an attached ‘integrator unit’. The undulations or unevenness values of pavement surface is measured using the ‘Fifth Wheel Bump Integrator’ and are expressed in terms of ‘Unevenness Index’ or ‘Roughness Index’ in mm per km road length or m/km.

Therefore the UI value is calculated for the test stretch, using the following relation:

$$UI = (10*B*R) / W \text{ (mm/Km)} \quad \ldots 5.1$$

The unevenness index value is converted in to IRI by using the following formula,

$$IRI = [(UI)/630]^{1/1.12} \quad \ldots 5.2$$

Where

UI = Unevenness Index, mm/km

B = Bump Integrator readings from the field, after setting initial reading to zero

R = Number of revolutions of the test wheel per km (The value of R of the standard Bump Integrator equipment in India is 460)

W = Number of field revolutions from the field

5.4 Measurement by Hawkeye 2000

The road roughness measurement made by Bump Integrator is a manual method. While the present study also involved the roughness and pavement condition estimation by a pavement condition rating van i.e. road survey equipment called **‘IRSM HAWKEYE 2000 Network Survey Vehicle’** as shown in figure. 5.1. The current method records pavement surface video images at highway speed by using this specially equipped van that is outfitted with high resolution cameras. The evaluation is either done manually by playing the video back on specially designed workstations while trained crew’s rate the recorded road surface or automatically by computer software.

Figure 5.1. Showing ISRM Hawkeye 2000 Professional Network Survey Vehicle

5.5. Traffic Volume Counts

Traffic Counts were conducted manually, by engaging adequate number of enumerators. The vehicles were classified as representative vehicles such as Two Wheeler (TW), Passenger Car (PC), Bus (BUS), Light Commercial Vehicle (LCV), Medium Commercial Vehicles (MCV), and Heavy Commercial Vehicles (HCV). The traffic data was collected on both the left and right wheel path. The collected data is a classified volume count (motorized and non-motorized vehicles) observed for duration of ten hours. Both the morning peak and the evening peak hour data was extracted along with off peak hours. In the present analysis, only the number of commercial vehicles of laden weight of 3 tonnes or more will be considered i.e. the vehicles or traffic volume that accounted for the gradual increase in axle loads. The vehicles not covered under the representative vehicles defined were suitably clubbed with the vehicles similar to them in composition and speed.

5.6. Measurement of Deflection by Benkelman Beam

In the present study measurement of Pavement Deflection is based on testing under a static load. Thereby, in the method a standard truck having a rear axle weight of 8170 kg with a dual tyre inflated to a pressure of 5.60 kg/cm^2 is used for loading the pavement. The total load and the tyre pressure during the actual test are maintained with a tolerance of +/- 1 percent and +/- 5 percent respectively. In each of the road section on the test stretch a minimum of ten points is marked at equal distance in each lane for making the deflection observations in the outer wheel path. The interval between the points should not be more than 50m. Since the selected stretch is having more than one lane the points marked on adjoining lane should be staggered. In the transverse direction the measurement points were considered at a distance of 1.5m from the pavement edge since it was four lane divided carriageway.

The deflections measured are influential to the varying parameters such as pavement temperature and the seasonal variations. Thereby at the time of design, all the deflection values are correlated to a standard temperature. If the temperature measured on the pavement surface is different than the standard temperature, corrections are to be applied. Also the pavement deflections do get affected by seasonal variation in terms of climatic conditions. The pavement deflections are considered when the sub grade of the soil is at its weakest condition. Hence the deflection measurement in Indian conditions is conducted during the monsoon season. If the measurement is not feasible during this period, a correction factor must be applied.

5.7. Use of GIS in Pavement Management Application (GPMA)

GIS based Pavement Management Application (GPMA) is a tailored computer application that provides technology and tools to assist in network programming of Highways Maintenance and Rehabilitation as well as project level design. In general, GPMA supports the following:

(1) Interactive and batch data entry and update.
(2) Querying, reporting and spatial displaying.
(3) Thematic representation of information.
(4) Maintenance Decision Support.
(5) Road maintenance needs and analysis.

PMMS starts with network identification and go through data collection, data analysis, maintenance priorities, maintenance decisions; and ends with supervision and follow-up. GIS starts with data entry and manipulations, thematic mapping, and ends with tailoring and decision support. GIS acts as the core for the integration process, through managing the different corresponding activities interaction. The integration interface is a transition level that exists to ensure adequate compatibility of integration requirements.

5.8. Digitisation of Bangalore City Map

The Bangalore city area map, Road network map taken from Bangalore Metropolitan Transport Corporation (BMTC) where selected road stretches are digitised as per requirement of GIS software Arc View 10.1 and Quantum GIS 1.8.0. After digitisation the respected road stretches then the data are inputed to the attribute table by linking the MS-Excel Sheets to show the data collected from the surveys conducted for all the five cycles. Finally the map has been imported in Quantum GIS 1.8.0, as shown in Figure 5.1.

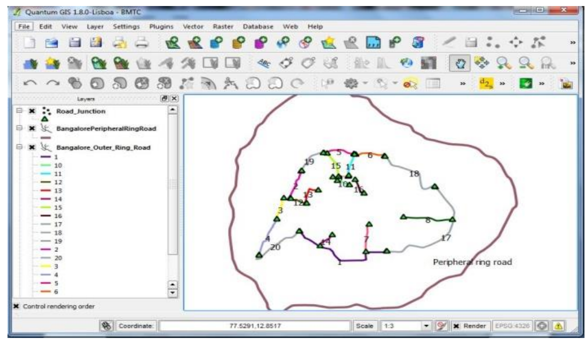

Figure 5.1. Showing the Bangalore Map after Digitisation

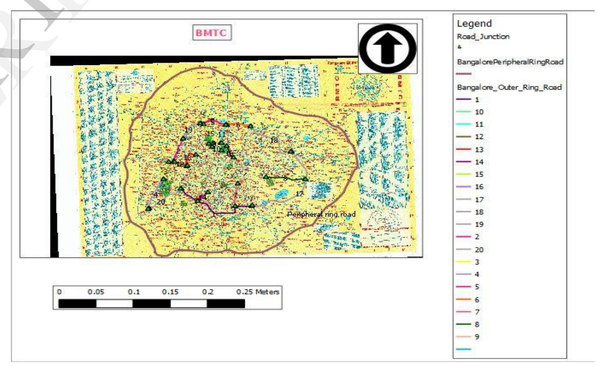

Figure 5.2. Final Stage for Printing

6. Results and Discussions

The data obtained from the following methods for the road stretch Hosur Road Silkboard junction to Nayandahally are tabulated in graphs as shown below.

In figure 6.1 shows the maximum traffic flow is 1950 PCU/hr. in the month of April 2012 and Roughness having the maximum value of 2893 mm/km as shown in figure 6.4, as well as Pavement Condition Index has led to minimum value of 15 as shown in figure 6.2. Due to the heavy traffic flow Rutting attained to a value of 10.8mm/km shown in figure 6.5 and BBD value of 0.9 as shown in figure 6.3.

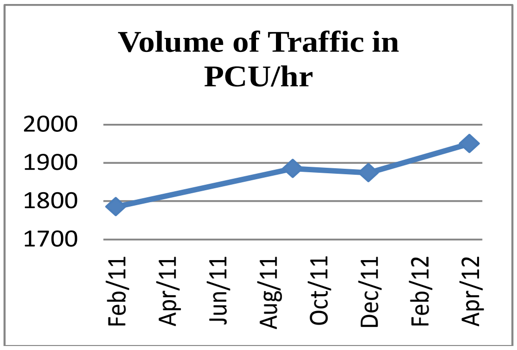

Figure 6.1. Volume of Traffic in PCU/hr

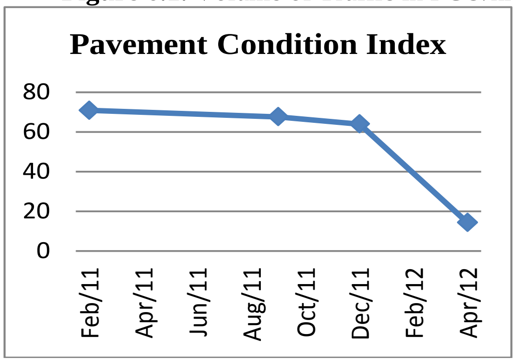

Figure 6.2. Pavement Condition Index

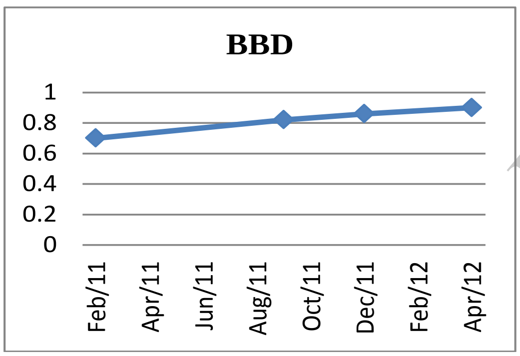

Figure 6.3. BBD

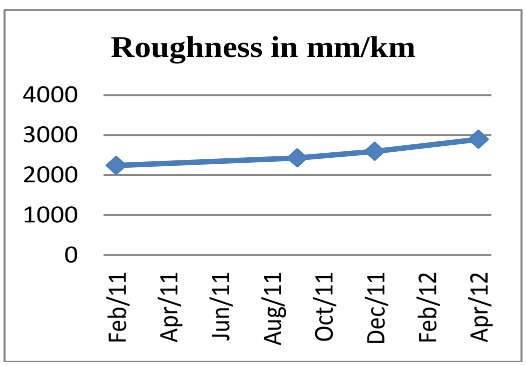

Figure 6.4. Roughness in mm/km

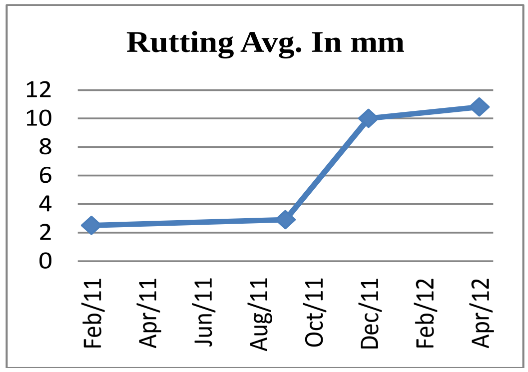

Figure 6.5. Rutting Avg. in mm

7. Outputs and Benefits

As we can see in the above graphs Volume of traffic has been increased from 1785 PCU/hr. to 1950 PCU/hr. in the month of April, 2012 and due to the increased traffic flow Rutting has been increased from 2.2 mm to 10.8 mm. Pavement Condition Index has been decreased from 70 to 15 and deflection has been increased from 0.7 mm to 0.9 mm. As we can see that the deflection value has not been increased more than 1 mm as per IRC 81-1997, “Guidelines for Strengthening of Flexible Pavements Using Benkelman Beam Deflection Technique”, thus reconstruction of pavement surface can be delayed until it crosses 1 mm.

The most important advantage of dynamic connection between the geographical data base and the attribute data is that each of the data base can be updated or modified separately. The data base needs to be updated for any change of geographical features. Pavement condition data changes with time and must be updated to reflect such condition changes.

Centralized data center will enhance the availability of various data and reduces repetition of data collection for the same road sections(s) by different road agencies, hence leading to saving of time and resources.

The study would lead to database development on GIS platform, development of intelligent queries and database tables which is useful for the design, maintenance and planning. Results of the study lead to planning of proper maintenance management system through database. This data base can be used for socio-economic and transport development of the region.

The society can enjoy smoother and efficient movement of traffic with reduced traffic delay on highways. With the database development for road planning and management, traffic movement will be efficient, effective and faster, allowing the road users to enjoy on road network from places to places. The subsequent pavement management system leads to efficient retrieval of information which enables decision makers in effective planning towards an efficient road and road transportation system. This would lead to faster socio-economic development of the country. PMMS results in better network pavement conditions; Network Maintenance/Rehabilitation priorities; cost effective repairs; strengthening measures and optimal utilisation of limited resources.

8. References

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