Geographical Information System for Pavement Management System

Dr. Neelam Jain
Scientist
Central Road Research Institute
New Delhi, India, 110020
neelamjn@crridom.org

Dr. P. K. Nanda
Area Coordinator
Central Road Research Institute
New Delhi, India, 110020
pknanda@crridom.org

Sh. B. K. Durai
Group Leader
Central Road Research Institute
New Delhi, India, 110020
durai@crridom.org

Sh. I. Prasada Rao
Scientist
Central Road Research Institute
New Delhi, India, 110020
Prasad@crridom.org

ABSTRACT:

In India, the large road network of about 3.3 million km length, created at a huge cost of approximately Rs. 5,20,000 crore is the life line of the country. It provides accessibility to different areas for movement of freight and passenger traffic across the country. The entire road network is 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 upgradation 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. Therefore there is a need to establish a centralized facility where information on road and road transportation can be utilized for the development of effective and efficient maintenance and rehabilitation measures and for planning upgradation strategies. The information which is available in bits and pieces with various agencies responsible for road construction and maintenance gets lost due to disorganized manner of its availability. Therefore there is a need for centralized platform which can meet this requirement.

CRRI is proposing to initiate a pilot scale project to establish the data center for roads and roads transport information management system. The GIS based pavement management system would eventually lead to the development of the frame work for GIS based Road Information Management System (RIMS) and pavement maintenance management system (PMMS). This paper reviews the role of GIS in pavement management system.

1. INTRODUCTION

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 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 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.

2. ROLE OF SPATIALLY INTEGRATED DATA IN PMS

Comprehensive pavement management models require a diverse collection of highway-related data including pavement condition surveys, skid resistance measurements, traffic counts, bridge inspections, sign inventories, photologging, accident investigation, construction and maintenance records and inventories of signs and roadside obstacles. Although these data may be available in digital format, they are typically unrelated to each other, duplicative and inconsistent. The various files may have been created independently of one another, using different referencing systems or computer formats. Popular referencing systems include milepost, reference post, paper document methods, state plane and latitude longitude. In the worst case, some of the data required for analysis may not be spatially referenced at all. As a result, they are difficult to use in a consistent and efficient manner as inputs to a PMS. GIS technology is proposed as a framework for data integration because it provides a means of relating data collected under various referencing systems.

3. GIS – PMS INTEGRATION FRAMEWORK

As with any management process, pavement management needs a decision support system to be effective. The decision support system functions range from information retrieval and display, filtering and pattern recognition, extrapolation, inference and logical comparison, to complex modeling. A GIS can be a very important decision support system element by facilitating the preparation, analysis, display, and management of geographical data. In a PMS, a GIS can greatly enhance the analysis and presentation of information. Figure 1 shows the typical PMS structure for a local situation. The database is the first building block of any asset management system, and it must include, at a minimum, the following informations:

- Inventory – basic physical attributes of the road network being managed
- Pavement Condition – periodic functional and structural evaluations to assess the level of service being provided to the user, and
- Maintenance and Rehabilitation strategies – strategies the agency uses to correct the problems. These are determined using the periodic condition surveys.

The database information is then analyzed to produce a multiyear maintenance and rehabilitation work program and budget, as follows:

- Network needs – the system will first assign all the maintenance and rehabilitation strategies for each road section in the inventory and narrowed down to the best strategy
- Prioritization – since the resources available are usually less than what the system needs, the resulting projects are ranked based on criteria consistent with agency objectives;
- Work program – using the list of prioritized projects, a multiyear maintenance and rehabilitation program is prepared; and
- Budget – the annual financial needs for executing the projects included in the work program are defined.

The last step entails the work plan and providing the necessary feedback process, that is, comparing the pavement and treatment performance with that predicted by the PMS, is crucial for improving the system's reliability.

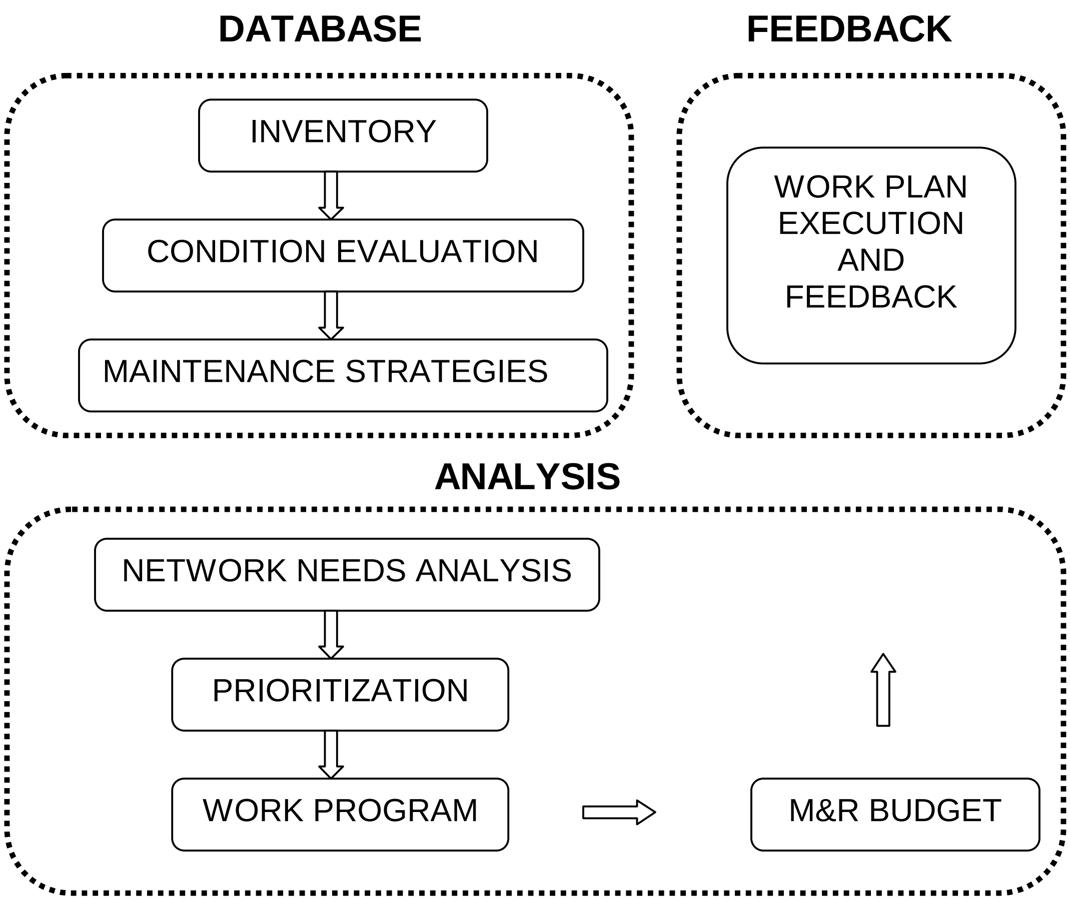

Figure 1 PMS Structure

4. GIS TECHNOLOGY AND BENEFITS

A GIS is a computerized data base management system for accumulating, storage, retrieval, analysis and display of spatial (i.e. locationally defined) data. A GIS contains two broad classifications of information, geocoded spatial data and attribute data. Geocoded spatial data define objects that have an orientation and relationship in two or three-dimensional space. Attributes associated with a street segment might include its width, number of lanes, construction history, and pavement condition and traffic volumes. An accident record could contain fields for vehicle type, weather conditions, contributing circumstances and injuries. This attribute data is associated with a topologic object (point, line or polygon) that has a position somewhere on the surface of the earth. A well-designed GIS permits the integration of these data. The sophisticated database in a GIS has the ability to associate and manipulate diverse sets of spatially referenced data that have been geocoded to a common referencing system. The software can transform state plane coordinates and milepoint data to latitude-longitude data and vice versa.

A GIS can expand the decision making on repair strategies and project scheduling by incorporating such diverse data as accident histories, economic needs hazardous materials shipment and vehicle volumes. A GIS can perform geographic queries in a straightforward, intuitive fashion rather than being limited to textual queries, A GIS/PMS can be used to build projects through spatial selection, can compute traffic impacts of various PMS plans and can incorporate the results of life cycle forecasts into measurements of future mobility.

4.1 Data Collection

In pavement management process first step is to collect and record the condition of the roadway segments. A series of computer displays showing the segments color-coded by the various attributes would greatly facilitate the process of data entry and editing. Omissions in the data collection effort would be immediately apparent from segments in the roadway showing no data. Errors in measurement or coding would also be readily apparent.

In electronic data collection, equipment makes it feasible to scan a roadway from a moving vehicle and automatically record pavement distresses on a microcomputer. If the data were to be entered directly into a GIS database, this procedure could produce an instant map display of the road condition.

4.2 Preliminary Analysis and Interpretation

In the traditional PMS, the highway engineer transfers some of this tabular information to a base map by hand as a step in understanding the data. For example, he might construct a map showing the severity of rutting or block cracking or create a map indicating the overall performance index. A GIS that integrates the database attributes describing the pavement condition with a cartographic display of the road network can be used to create any number of illustrative visual displays of the status of the road system.

4.3 Determination of Strategies and Assignment of Resources

The determination of strategies could imply a series of decision rules based on economic analysis that match deficiency ratings with appropriate actions. Well-designed GIS/PMS should have direct links to decision modules so that the strategies can be readily determined. The strategy module should have direct access to the GIS/PMS database, and the model results should be entered directly into the database.

A GIS would enrich the decision-making process by incorporating other types of data that could not easily be brought into the process without the ability to relate data spatially. One of the example is accident analysis requires the correlation of a number of explanatory roadway and environmental variables such as roadway geometrics, weather conditions, traffic volumes, signage, signalization, lighting, and pavement condition. A GIS can serve as the integrator of all transportation activities (e.g., pavement management, accident analysis, sign and signal inventories and planning), as well as the link to other agencies with overlapping data needs (e.g., planning, environmental resources, utilities).

5. ESSENTIAL COMPONENTS OF GIS/PMS

A number of essential analytical capabilities that should be included in comprehensive GIS/PMS have been identified:

- data base editor for storing and editing pavement condition data and other data to be used in the analysis;
- Formula editing of data base fields that facilitates the computation of new relationships such as an overall condition rating;
- Univariate statistics (min, max, sum, mean and standard deviation), e.g., to compute the total lane miles with a deficiency rating greater than 90; multiple regression to compute deterioration equations; correlation to compute dependence between possible explanatory variables such as truck volumes, weather, and soil conditions and pavement condition;

- Charting (e.g., pie charts and bar charts) to enhance the understandability of the data and make it easier to communicate results to decision makers, politicians, and citizen groups;
- Matrix tools for creating and manipulating origin-destination tables, travel time matrices, and other one and two-dimensional matrices used in transportation models for shortest path detour determination and traffic assignment;
- A set of useful transportation models and algorithms including shortest path, traffic assignment, vehicle routing (for efficient reallocation of trucks and equipment), and traveling salesman (for the delivery of materials to several construction sites); and
- Links to external procedures such as life cycle costing, decision analysis, shortest path, and traffic assignment.

6. CURRENT APPLICATION AND CASE STUDIES

Though the pilot scale project is being initiated now to establish a comprehensive database in GIS environment for roads and road information management system at the national level, small regional studies with limited scope have already been undertaken by the Institute.

Data for about 360 km under the jurisdiction of PWD and MCD roads under the study on evaluation of Delhi roads for maintenance and rehabilitation is being created in GIS environment. The existing road network map of Delhi has been prepared in GIS environment, from which the various categorized roads are identified and created as separate layers. The network being covered in the study is shown in figure 1. The various field surveys were carried out to collect the highway condition data. A computer database is used to sort and store the collected data and attached to the relevant layers in GIS environment. Figure 2 shows the pavement condition, roughness, traffic and axle loading scenario on PWD Roads (a typical zone map). A simple criterion has been used to evaluate repair or preservation strategies for 10 years for the selected network. Figure 3 shows the year wise maintenance strategies of the inner ring road.

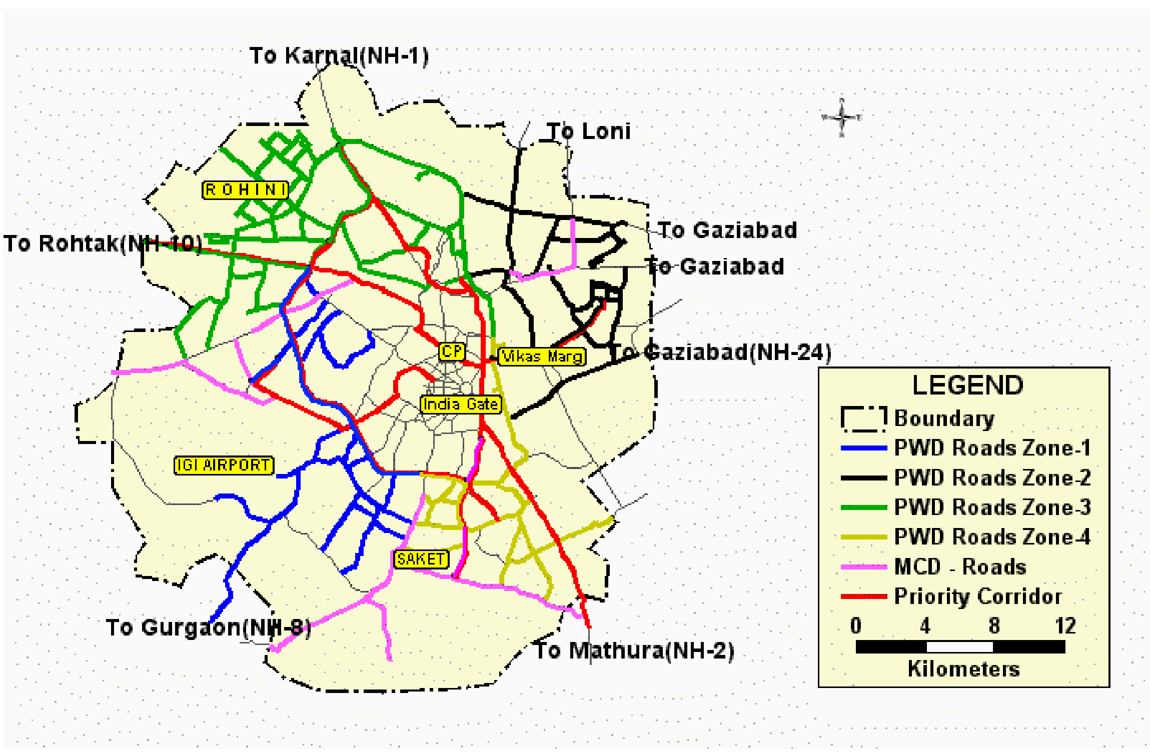

Figure 1: Road Map of Delhi

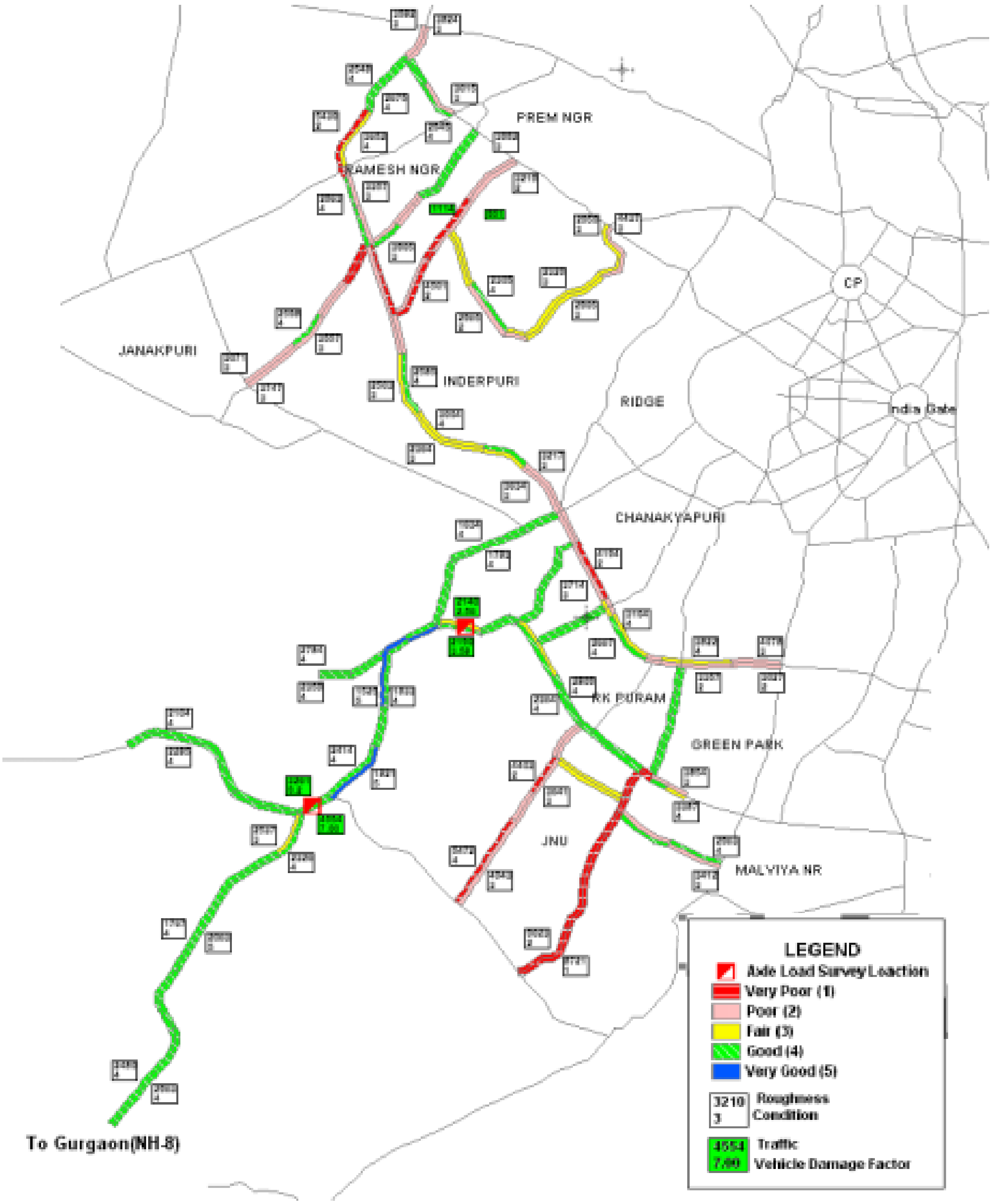

Figure 2: Pavement Condition, Roughness, Traffic and Axle Loading Scenario on PWD Roads (Zone – 4)

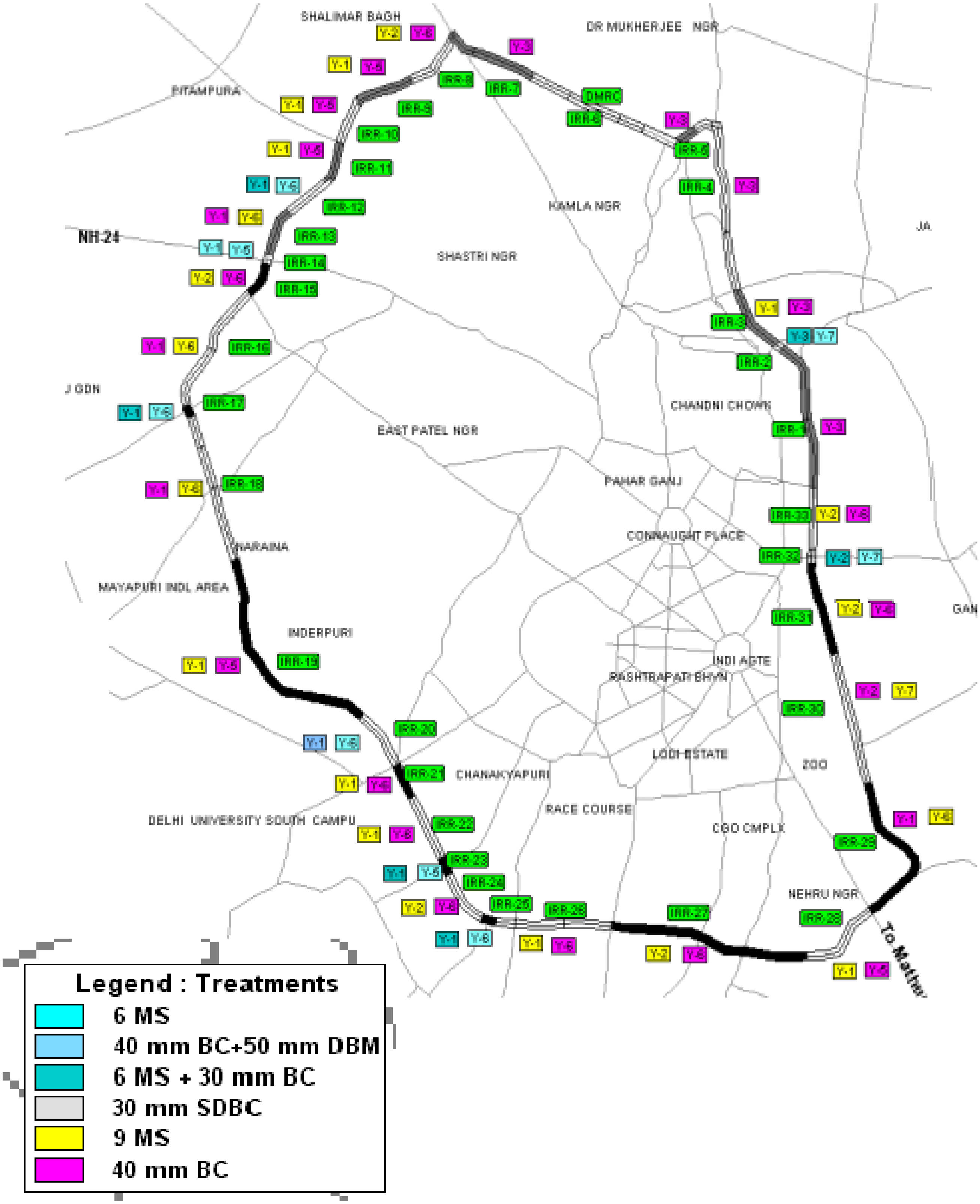

Figure 3: Year wise Maintenance and Rehabilitation for Inner Ring Road

7. CONCLUDING REMARKS

GIS can be a very important tool in a decision support system by facilitating preparation, analysis, display, and management of highway data in a geographical platform. In particular, pavement management is a decision process that could benefit from the use of a geographical platform provided by GIS, because road networks are inherently geographic. Spatial considerations are not only essential in analyzing the different road related activities, but also can vastly improve the quality of the decision-making process.

ACKNOWLEDGEMENT

The authors are grateful to Prof. P. K. Sikdar, Director, Central Road Research Institute for kind permission to publish the paper. Authors are also thankful to Dr. P. K. Kanchan for the help rendered by him.

BIBLIOGRAPHY

1. Kassabian, N.C., Tobias, A.G. et al, “Geographical Information Systems”, *Transportation Research Board, Highway and Facility Design,* Report 1261, 1990.
2. Dhingra, S. L, Sikdar, P. K., and Singh, A. K., “GIS Technology for Transportation Network Information System and Management*”, Seminar on perspective planning for road development in India, Indian Road Congress*, Vol. 1, Oct. 7-8, New Delhi, PP. 1169-1185.
3. Swan, A. R. H., and Sandilands, M., “Introduction to Geological Data Analysis”, Blackwell Science, 1995.
4. Barton, Y et al, “Geographical Information System Supplement to Civil Engineering”, *Proc. of the Institute of Civil Engineers*, Vol. 114, Special issue 2, 1996.
5. Kraft, D. C., Valencia, J., “Integration of Roadway Management System (RMS) and Geographic Information System (GIS) for Economic and Strategic Assessment of Pavement Performance”, *9th Symposium on GISs for Highway Engineering Exchange Program, Transportation Research Board,* PP. 363-383, 1996.
6. McPherson, L., Shuller, E., Rosendahl, F. and Tilley, C., “A GIS Application used for Highway Safety Studies*”, 9th symposium on Geographic Information Systems for of Regional Councils, Transportation Research Board*, PP. 324-351, 1996.
7. Ghanem, M. A., “Application of GIS in Short and Long Range Transportation Planning”, *Proceedings of the 1994 Geographic Information Systems for Transportation (GIS-T) Symposium,* PP. 368-375, 1994.
8. Hartgen, D. T., Li., Y., “Geographic Information Systems Applications to Transportation Corridor Planning”, *Transportation Research Record (1429),* PP. 57-66, 1994.
9. Petzold, R., “Yielding the Benefits of GIS”, *American City and Country, 109(3),* PP. 56-63, 1994.
10. Marsh, P. J. and Kerali, H. R., “An Expert System to Integrate Highway Maintenance Systems with Geographical Information Systems”, *Geographical Information Systems, Proceedings of Seminar N Held at the PTRC European Transport Forum, University of Warwick, England, 12-16 September*, Vol. P385, PP. 81-92, 1994.
11. Howarth, G., “(Highways maintenance) maintain Accuracy”, *Highways, 61(2),* PP. 8, 1993.
12. Bristow, N., “Using New Technology: Its Application to Road Design”, *Routes/Roads, (277),* PP. 28-29, 1992.
13. Antenucci, J. C., Brown, K., Croswell, P. L., Kevany, M. J. and Archer, H., “Geographical Information Systems: A Guide to the Technology”, *Transportation Research Board,* PP. 315, 1991.
14. Heine, M., “All Size Cities Benefit from GIS Use”, *Roads and Bridges, 29(3)* , PP. 68, 1991.
15. Hayashi, Y., Omar, O. and Kawamata, K., “A GIS Based Highway Network Deterioration Analysis”, *Highways, Proceedings of Seminar L held at the PTRC European Transport,*

Highways and Planning 19 th Summer Annual Meeting, University of Sussex, September 9-13, Vol. P351, PP. 137-150, 1991.

16. Dildine, G. and Scott, R. H., “Utilization of Operations Geographic Information Systems (GIS) for Incident Management”, *Road Transport Informatics/Intelligent Vehicle – Highway Systems 24 th ISATA International Symposium on Automotive Technology and Automation, Florence, Italy, 20-24 May,* PP. 679-686, 1991.
17. Allen, A., “Utilizing GIS Concepts in Roadway Project Development”, *Federal Highway Administration, Proceedings of the 1990 Geographic Information Systems,* PP. 3, 1990.
18. O’Neill, W. A. and Akundi, B., “Automated Conversion of Milepoint Data to Intersection/ Link Network Structure: An Application of GIS in Transportation”, *Transportation Research Board, (1261),* PP. 27-34, 1990.
19. Fernando, E., Paredes, M. and Scullion, T., “An Initial Evaluation of the Feasibility of a GIS to Support PMS Applications Interim Report”, *Texas Transportation Institute, U.S.A., Report No. TX-90-930-4, 870900-8908,* PP. 80, 1989.