CHAPTER ONE
INTRODUCTION

1.1 PREAMBLE

Road usage in Nigeria in the past four decades has been a fast-paced growth area and may remain so for some time to come. This is especially true as the other modes of transportation, notably the railway system, is comatose.

Throughout the world, there is a widespread recognition of the importance of highway maintenance and as such, high value is placed on it, both by users and other stakeholders. There is also an increasing understanding of the adverse consequences of failure to invest adequately and effectively in the management of the local highway network, which include progressive reduction in safety and quality of highway pavement structure. This negligence often times engenders greater levels of investment in the future.

There are wider consequences as further elucidated: - The highway network is an important and highly visible community asset, supporting the national and local economy and contributing to the character and environment of the areas that it serves. The potential contribution of the local road network however extends very wide, beyond the transport sector. It is fundamental to the economic, social and environmental well being of the community and its management and maintenance should seek to maximize this wider contribution. Effective management of the local road network has the potential to aid regeneration, social inclusion, community safety, health and the environment but this will need a planned long term programme of investment, efficiently managed and supported by effective technical and management systems [CPMM, 2001].

Despite all efforts by the governments, road maintenance in Nigeria has remained an intractable problem during much of the period spanning the development of the national road network. Under-funding, institutional constraints and enthusiasm for construction with little or no maintenance programmes have led to the poor condition of the road network.

1.2 OVERVIEW

The total length of public roads in the nation's network is currently estimated at about 194,000 kilometres, with the federal government being responsible for about 17 percent, state governments

16 percent and local governments 67 percent [FMWH, 2000]. Details of the distribution and their conditions are given in Table 1.1.

However, these roads have been plagued by a number of problems, with the major ones being faulty geometric and pavement designs, inadequate construction, unregulated axle loading, inadequate drainage system and poor maintenance culture, which have significantly reduced the utility of the roads. There are potholes, degradation of pavements, fallen bridges, etc, along most Nigerian roads. These problems have made it difficult, expensive and more arduous to move products and services from producers to consumers, farm produce from rural to urban centres, which often lead to loss of man-hours and high cost of goods and services.

TABLE 1.1: DISTRIBUTION OF THE NATIONAL ROAD NETWORK AS AT 2000

Type of Road	**Federal (km)**	**State (km)**	**Local Govt. (km)**	**Total (km)**
Paved Trunk Roads	26,500	10,400	-	36,900
Unpaved Trunk Roads	5,600	20,100	-	25,700
Urban Roads	-	-	21,900	21,900
Main Rural Roads	-	-	72,800	72,800
Village Access Roads	-	-	35,900	35,900
Total (km)	32,100	30,500	130,600	193,200
Percent	17%	16%	67%	100%

Paved Roads		**Rating Proportion**		
Type	**Total Length (km)**	**Good**	**Fair**	**Poor**
Federal Roads	26,500	50%	20%	30%
State Roads	10,400	30%	30%	40%
Local Govt. Roads	21,900	5%	20%	75%

Unpaved Roads		**Rating Proportion**		
Type	**Total Length (km)**	**Good**	**Fair**	**Poor**
Federal Roads	5,600	6.0%	56.6%	37.4%
State Roads	20,100	7.0%	49.5%	43.5%
Local Govt. Roads	108,700	4.2%	38.4%	57.4%

Source: Road Vision 2000 Steering Committee Information Brochure, Pp 4 Transport in Nigeria in 2020

The major road transport infrastructure in Nigeria consists of 34,340.95 km of federal highways including seven major bridges across the Niger and Benue Rivers, the Lagos ring road and the third Lagos mainland axial bridge [FMWH, 1999], and also 30,500 km of state roads, and 130,000 km of local roads. As at June 1996, only 50% of the federal roads and 30% of the state roads were in reasonably good condition. Only an estimated 5% of the local rural roads were freely motorable. That is only about 12% of the national road network is in reasonably good condition. Meanwhile, repeated use and lack of maintenance further erode the rest of the federal highway network.

As itemized from Road Vision Steering Committee Information Brochure [Road Vision, 2000], the failure to reform the existing system to meet the present day realities and challenges has put this country's investments in roads in jeopardy to the point where:

- less than 50% of the national road network are today in good or fair condition;
- the road assets is estimated to be suffering an annual loss of value of about ₦80 billion due to lack of maintenance; and
- road users suffer additional vehicle operating costs of ₦53.8 billion per annum due to poor condition.

The above total financial loss of about ₦133 billion per annum represents about 5.5% of Nigeria's 1994 Gross Domestic Product (GDP). Other losses that are traceable to the poor condition of roads include (unquantifiable) economic losses from road accidents, loss of productive man-hours in traffic, emotional and physical trauma people go through plying the roads and the consequent loss in productivity, etc.

In Nigeria today, a considerable number of the populace live away from an all weather road. Neglect of road maintenance multiplies the cost of repair by 200% - 300% after every rainy season, and increases cost to vehicle owners and shippers by more than 50% for paved roads and much more for gravel and earth roads. The implication of this to manufacturers and producers is grievous, to say the least. It increases cost of production and makes goods and produce made in Nigeria less competitive in both domestic (because of trade liberalization and Nigeria's entry into the World Trade Organization) and international markets [Buhari, 2000].

According to a Nigerian writer [This Day, 2004], despite the 4.7 billion naira allocated to road maintenance in the year 2003 budget, there is nothing to show for it in terms of improvement on the condition of roads. This calls for a greater emphasis on accountability and professionalism in road maintenance activities in Nigeria. The days, for the foreseeable future, of ad-hoc surface dressing or laying a wearing course to improve the visual condition should be a thing of the past. Maintenance funding in the future will need to show a benefit to the public in some tangible form.

1.3 CONDITION OF THE FEDERAL HIGHWAYS

A (windshield) survey of the state of highways in the country was conducted for two weeks by the Task Force for Road Maintenance (set up by the Federal Government) from September 2, 2002. The purpose of the survey was to gather pertinent information on road construction/maintenance in Nigeria and also to do an on-the-spot assessment of the state of roads nationwide. The survey was conducted along the six geo-political zones of the country, for convenience of coverage. The zones are South-South, South-East, South-West, North-East, North-West and North-Central.

The survey indicated that most of the roads especially in the Southern areas were in very poor condition, and requires complete rehabilitation [CBN, 2003]. The story is relatively the same with the roads in the Northern Zones. Some roads constructed over 30 years ago have not been rehabilitated for once, resulting in major cracks (longitudinal and transverse), depressions, broken down bridges and numerous potholes that make road transport slow and unsafe. On many roads, the shoulder, a major component of the road had eroded off, putting the roads in near impassable condition. Some of the roads require total rehabilitation and asphalt overlay, reinstatement of the shoulders, filling of potholes and building of collapsed bridges.

The second problem is that funding of road maintenance has been grossly inadequate. Table 1.2 shows that from 1999 to 2002, less than 10 per cent of the annual funding request made by the FMW&H for road maintenance was appropriated. On the average, only 4.9 percent of the amount required for the period was released. Collections from tollgates across the country totalled N569.29 million, N742.72 million and N779.84 million in 2000, 2001 and 2002 respectively. For each year, tollgates collections alone were much higher than the total funds released for road maintenance (see Table 1.2).

The survey by the Task Force for Road Maintenance also revealed that from February 1997 to December 2001 (no data for 2002), a total of 96 road contracts, mainly rehabilitation, reconstruction and expansion, were awarded by the Federal Ministry of Works, at a total contract sum of N186.999 billion. Of the total, 20 contracts worth N40.24 billion were for the South-South Zone, 19 contracts worth N35.346 billion in the South-West, 18 contracts valued at N45.l22billion in the North Central, 14 contracts worth N26.774 billion in the North- East, 13 contracts valued N21.603 billion in the South- East and 12 with the contract sum of Nl7.915 billion in the North-West.

TABLE 1.2: APPROPRIATIONS FOR ROAD MAINTENANCE (1999 – 2002)

YEAR	AMOUNT PROPOSED (1) =N=	AMOUNT APPRO-PRIATED (2) =N=	AMOUNT RELEASED (3) =N=	APPRO-PRIATION AS A PERCEN-TAGE OF PROPOSAL (4) %	RELEASE AS A PERCEN-TAGE OF APPRO-PRIATION (5) %	RELEASE AS A PERCEN-TAGE OF PROPOSAL (6) %
1999	5,000,000,000	470,895,625	470,895,625.0	9.42	100.0	9.42
2000	10,000,000,000	450,000,000	401,171,769.0	4.5	89.2	4.0
2001	5,600,000,000	1,656,000,000	474,493,008.0	29.6	28.7	8.5
2002	10,307,931,221	274,000,000.0	178,688,448.7	2.7	65.2	1.7
TOTAL	30,907,931,221	2,850,895,625	1,525,248,850	9.2	53.5	4.9

Source: CBN Research Department Occasional Paper No. 27, April 2003.

The third reason why the state of Nigerian roads has remained poor is the excessive use of the road network, given the undeveloped state of waterways and the poor state of the railways, which are alternative transport modes. In particular, the railways should be serving the purpose of transporting bulky and heavy goods, which are not appropriate for road haulage. The transportation of bulky and heavy goods on our highways translates to excessive axle loading which result in damaging effects on the pavements.

As the fourth reason, information from some Federal Ministry of Works officials showed that there is no articulated programme for road maintenance. Road maintenance decisions are taken at the headquarters and are in most cases influenced by politics and not necessarily on the actual maintenance needs. For this reason most of the roads have been neglected.

1.4 MAINTENANCE AND REHABILITATION OF PAVEMENTS

Soon after initial construction, roadways begin to deteriorate due to traffic and environmental factors. All pavements will deteriorate over time. The deterioration of a pavement results from a number of causes and can occur at different rates. Typically, pavement deteriorates at an ever-increasing rate: at first very few distresses are present and the pavements stay in relatively good condition, but as it ages, more distresses develop, with each distress making it easier for subsequent distresses to develop. For instance, once a substantial crack occurs, it is then easier for water to (i) infiltrate the hot-mix asphalt (HMA) layer and (ii) penetrate and weaken the subgrade. Data indicate that the deterioration of a roadway pavement will follow a fairly predictable pattern, for a given traffic and environmental conditions (APWA, 2004).

The rate of pavement deterioration accelerates with increasing age and traffic. As the deterioration continues, the cost of the rehabilitation increases dramatically. Studies have indicated that if a roadway is maintained, at an acceptable level of service, it will ultimately cost the owner less. A World Bank study indicates that each $1.00 expended at the first 40 percent drop in roadway quality will result in a savings of $3.00 to $4.00 compared to the expenditure which would be required at the 80 percent drop in quality, as indicated in Figure 1.1 [ARRA, 2001].

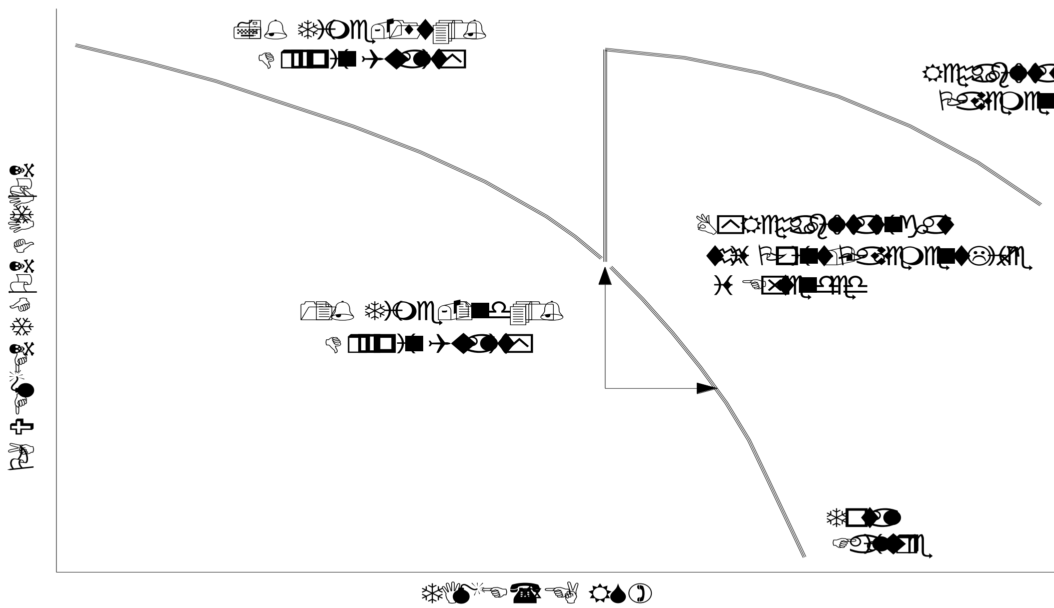


Figure 1.1: Pavement Deterioration and Recycling Rehabilitation versus Time

Source: Basic Asphalt Recycling Manual [ARRA, 2001]

If no preventive maintenance or rehabilitation is undertaken at the appropriate times, the roadway will quickly deteriorate to the point where expensive reconstruction will be the only option. Fortunately, with the timely application of preventive maintenance and rehabilitation activities, significant extensions to the roadway's service life can be achieved, as indicated in Figure 1.1 [ARRA, 2001].A wide variety of preventive maintenance and rehabilitation procedures exist which can be used individually or in combination to form a strategy to extend the service life of the pavement, in the most cost effective manner.

Maintenance and rehabilitation are the two principal treatments used to extend pavement life. These treatments will (i) immediately improve the pavement condition and (ii) affect the future rate of deterioration. In general, maintenance can slow the rate of deterioration by correcting small pavement defects before they can worsen and contribute to further defects. Beyond a certain point, however, defects become too large for correction by mere maintenance. At this point, rehabilitation can be used to effect a wholesale correction of a large number of relatively severe defects, which provides a step increase in pavement quality [APWA, 2003]. Figure 1.2 illustrates this concept.

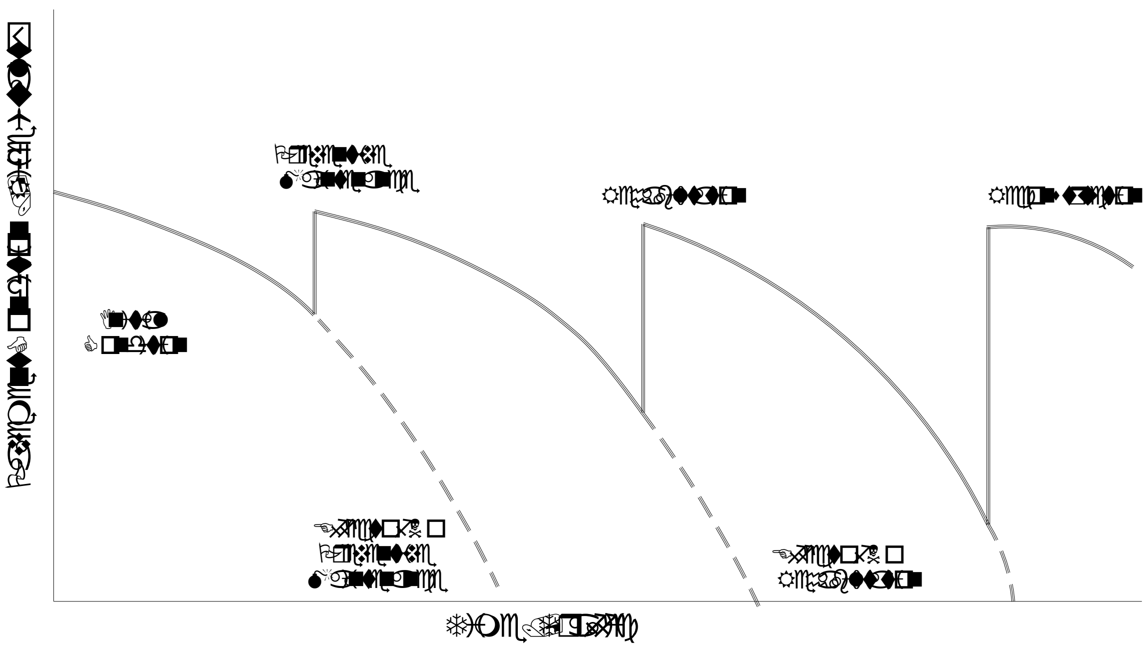


Figure 1.2: Pavement Deterioration versus Time
Source: Basic Asphalt Recycling Manual [ARRA, 2001]

1.5 PAVEMENT INFORMATION AND MANAGEMENT SYSTEM (PIMS)

Pavement management is basically concerned with the identification of the threshold condition of existing pavement. Threshold condition is the minimum level to which any part of or section of the highways is permitted to deteriorate before maintenance is initiated to return the part or section to as-built condition. Pavement management system includes but is not limited to systematic procedures for scheduling maintenance and rehabilitation activities based on optimization of benefit and minimization of cost (life cycle cost).

The American Association of State Highway and Transportation Officials (AASHTO) Guidelines for PIMS (1990) defines PIMS as “a set of tools or methods that (can) assist decision makers in finding cost-effective strategies for providing, evaluating and maintaining pavements in serviceable condition". The objective of pavement management is to constantly study or evaluate the service performance or what takes place between the initial construction and before failure. It is the period of preventive maintenance or preservation of the pavement in order to assist pavement live up to its design life.

PIMS assists in providing answers to the following questions [AASHTO, 1990]:

- ❖ What general maintenance and rehabilitation (M&R) strategies would be the most cost-effective?
- ❖ Where (what pavement sections) are M&R treatments needed?
- ❖ When would be the best time (condition) to program a treatment?

In addition, a PIMS 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 [FHWA, 1993]. To effectively support these types of decisions, a PIMS must include reliable and sufficient data; calibrated analysis models and procedures; and effective, easy-to-use tools that help visualize and quantify the impact of the possible solutions considered.

Although the approaches used by highway agencies differ, the foundation of all PIMS is a database that includes the following four general types of data:

1. Inventory (including pavement structure, geometrics, and environment, among others);
2. Road usage [traffic volume and loading, usually measured in equivalent single-axle loads (ESALs)];
3. Pavement condition (ride quality, surface distresses, friction, and/or structural capacity); and
4. Pavement construction, maintenance, and rehabilitation history.

PIMS analysis capabilities include network-level and project-level tools. "Network-level" analysis tools support planning and programming decisions for the entire network or system. According to Flintsch [2003], a PIMS 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 the 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, the network-level goals and available budgets are defined by higher-level strategic decisions that set the overall goals for system performance and agency policies. PMS produce reports and graphic displays that are tailored to different organizational levels of management and executive levels, as well to the public.

1.6 PROBLEM STATEMENT

Currently, there is no comprehensive management system for inspecting, recording, analyzing, prioritizing and programming highway maintenance works in Nigeria. The ability to integrate data from a variety of sources and provide summarized, strategic information in an easily understandable format for decision makers is also lacking.

There is need to digitize all available information including cost of maintenance and continuous condition survey data for all the federal highway sections. Available data are scanty and still in paper form (Appendices G - I).

1.7 RESEARCH GOAL AND OBJECTIVES

In order to move the nation forward, there is the need to obviate the problems of poor maintenance and inefficient management of highway pavements in Nigeria. Towards this end, the goal of this research is **to develop a computerized network-level Pavement Information and Management System (PIMS) that can assist in evolving cost-effective strategies for constructing, evaluating and maintaining highway pavements**. It entails the development of a simplified method to gather information and to generate the maintenance, rehabilitation, and reconstruction actions with a view to improving highway pavement performance based on certain acceptable indices.

The achievement of the research goal shall be pursued under three specific objectives, namely:-

- to evolve and validate a computerized condition rating system / M&R procedure within the proposed PIMS, applicable to all highway sections.
- to develop performance prediction models capable of estimating present and predicted performance of any selected highway section alongside user and intervention costs models, for network-level.
- to design an interface within the ArcView and Visual Basic environment that would be capable of displaying trend of past and present activities and provide information in thematic maps, charts and graphs.

1.8 SCOPE AND LIMITATIONS OF WORK

The scope of work shall include the following activities:

- The development of a PIMS that is functional at network level to provide condition rating for surveyed roads.

- The rating system adopted is the pavement condition index (PCI) method. Although the twelve roads selected for survey/validation of the automated rating system were coincidentally from the North Central part of Nigeria, the system is applicable to any highway section.

- Probabilistic performance/costs modelling of surveyed roads was carried out based on current roughness data and transition probability matrices which were derived from subjective judgements of pavement maintenance experts.

- The digital map digitized for use in the PIMS is accurate only to the accuracy level of the available old paper maps and FMWH inventory of roads [FMWH, 1999].

- Ecological parameters could not be incorporated in the modelling at this stage and as such, only engineering variables were utilized. It is planned to incorporate ecological parameters in the post-doctoral work.

1.9 SIGNIFICANCE OF STUDY (RESEARCH CONTRIBUTIONS)

The expected research contributions are highlighted as follows:

1. If properly utilized, the developed system would be very effective in managing the pavements in the federal road network, at the network level. It would also be very useful in assisting pavement engineers and decision makers in planning, programming and budgeting.

2. It is believed that timely intervention to maintain pavements at appropriate threshold levels, using the developed PIMS, will significantly reduce the overall expenditure for both the road users and the government.

3. Through the development of this PIMS, and regular measurement of the condition rating of pavement sections over the years, it shall be possible to develop more accurate pavement deterioration modelling (using historical data).

4. The effect of pavement age and traffic volume in the pavement deterioration profile was captured through incorporation in the developed transition probability matrices.

5. The computerized PIMS is designed to archive historic data. Graphs, charts and thematic maps for pavement variables such as PCI, ADT, M&R Actions and Costs, etc., can be generated for historic and predicted data. Thus the condition and performance of the highway network can be observed over several years.

6. The PIMS will be able to assist decision-makers in the government to evaluate the impact of distribution of funds for M&R activities of all road sections. Evaluation can be done at state or zone level.

1.10 OPERATIONAL DEFINITION OF TERMS

Some of the technical terminologies employed in this work are briefly defined as follows:

Pavement: The term pavement is used in this report to mean the whole road structure with all of its layers and not just the surfacing layer.

Flexible Pavement: A pavement type in which bituminous mixtures are used as surfacing materials.

Pavement Performance: Pavement performance is a measure of the in-service condition of the pavement. Performance is often expressed in two ways: structural and functional.

Pavement Deterioration: This represents a negative change in performance or condition of the pavement, i.e, an increase in distresses or decrease in serviceability.

PIMS: Pavement Information and Management System (PIMS) can be 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 serviceable condition.

M&R: Maintenance and Rehabilitation (M&R) strategies and actions are used to restore a pavement to adequate level of service.

PCI: Pavement Condition Index (PCI) can be defined as an index reflecting the composite effects of varying distress types, severity level, and extent upon the overall condition of pavement. PCI values range from 0 to 100, which are defined as failed and excellent condition, respectively.

TPM: Transition Probability Matrix (TPM) can be used to represent a system with a finite (N+1) number of states, labelled 0, 1, 2, … N and it is assumed that the system is always in one of these states while transition is in discrete steps.

MATLAB®: Matrix Laboratory (MATLAB) is a high-performance language for technical computing developed by The Mathworks Inc (TM). It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Matlab was used to carry out all the mathematical computations in this work.

Visual Basic: Microsoft's Visual Basic is a programming language developed by Microsoft Corporation. It is an extremely powerful application development tool. Visual Basic's strength lies in its ability to display graphics. The results and generated reports in this work are displayed within Visual Basic interface.

Arc View: This is geographic information system (GIS) software for visualizing, managing, creating, and analyzing geographic data. With ArcView, the user can understand the geographic context of data, allowing the user to see relationships and identify patterns in new ways.

1.11 THESIS LAYOUT

Following this introduction in chapter 1, the second chapter focuses on a review of the key aspects contributing to the development and implementation of different types of PMS. Road network referencing system, field data collection for PIMS, pavement condition rating, professional PIMS software, and development of pavement performance/prediction models, are some of the areas that were reviewed.

The third chapter is devoted to the development of pavement evaluation based on the PCI methodology. Graphical user interfaces (GUI) were created in MATHLAB/Visual Basic software environment to perform activities such as recording of road inventory, recording of condition survey data and computation of condition rating. Other interfaces needed to perform various spatial and temporal analyses and displays were also created. Chapter Three also contains pavement performance and user cost prediction modelling. Models were programmed within the Matlab/Visual Basic platform to predict pavement deterioration and user costs. The programmed models are capable of generating deterioration profiles for three maintenance options.

Chapter Four is dedicated to the analyses and discussion of results. The summary of findings, conclusion, recommendations and contributions to knowledge are presented in chapter five.

CHAPTER TWO

LITERATURE REVIEW

2.1 OVERVIEW

There are many aspects of PIMS. Some of the basic steps usually involved in the development and implementation of a PIMS include: Defining the Roadway Network, Gathering Roadway System Data, Gathering Pavement Condition Data/Predicting Pavement Condition, Developing Short-Term/Long Term Rehabilitation Strategies, Documenting and Reporting Results, among others.

Thus, in order to do justice to the literature review, the key aspects contributing to the development and implementation of different types of PIMS by different agencies were highlighted and reviewed. Road network referencing system, field data collection for PIMS, pavement condition rating, professional PIMS software, GIS-based PIMS, development of pavement performance/prediction models, multiple-year prioritization and optimization are some of the areas that were reviewed.

2.2 ORIGIN OF PAVEMENT MANAGEMENT SYSTEMS

Pavement management systems started with the AASHO Road Test from 1956 to 1960. The road test staff determined that it would be necessary to evaluate the performance of pavements in a way that would be independent of pavement type and that could have universal application for describing a pavement's condition. The method developed and used at the road test was based on a pavement's present serviceability (riding comfort) [Finn, 1997].

The working hypothesis for the development of present serviceability was based on the assumption that riding comfort, along with safety, were the primary performance objectives associated with pavements. The problems were how to estimate riding comfort without having to actually ride over every section on the road test every two weeks and how to translate this concept for application by relevant agencies.

The solution was simple in concept, as described by Carey and Irick [1960]. First is assembling a group of people to ride over selected sections and getting their respective opinions on the ride quality of the section. Second is obtaining physical measurements of the condition for each of the sections, and third is correlating the subjective responses with the physical measurements.

2.3 DATA COLLECTION ACTIVITIES FOR PIMS

Data collection activities are part of the key aspects of the pavement management process. The principal data collected for a PIMS include road inventory, pavement structural and functional conditions, traffic (volume and weights), and maintenance / rehabilitation history. The more detailed these information are, the better and more detailed analyses a GIS system (if adopted) can carry out. However, this information is usually very voluminous and painstaking to capture, record and disseminate. In most DOTs in U.S., automated data collection equipment is used to acquire at least part of the inventory and condition data [AASHTO, 2001].

2.3.1 GENERATING DIGITAL ROAD NETWORK MAPS

Usually, the first aspect of digital management of infrastructure such as road network has to start with producing existing road network map in digital format. Many methods have been variously adopted over the years including conversion of hard copy maps (produced with manual cartographic techniques and updated using ortho-photography) into digital format [Higgins, 1996]. Existing maps have also been converted using large format tablet digitizers, personal computer and software such as Arc/Info® software. There is also a record of Global Positioning System (GPS) and video being used to obtain centreline survey of 28,000km long national road network in the Philippines [Lagunzad, et al., 2003].

2.3.2 REFERENCING SYSTEMS

The primary purpose of the referencing system is to accurately define and identify the road network. The reference, or indexing, system used by a PIMS affects the utility of the system. The data used for PIMS are located and stored according to two main methods: (1) using management units (e.g., link/node) or (2) based on a location referencing system. In the first method, the limits of the management units or sections are identified before data collection, and the information is stored by section. This method is simple, but it has problems when section limits change. In addition, it is not very practical when automated data collection is used. The second method consists of collecting data using the referencing method most appropriate for the data being collected (e.g., reference point/offset measured using distance measuring instruments (DMIs) for automated pavement evaluation vehicles). This method facilitates automated data collection, but the data has to be linked to a specific management unit or section through some additional processing using a location referencing system [AASHTO, 2001].

Traditionally, PIMS data collection has used linear location referencing methods, such as route name and mile-post/logpoint [AASHTO, 2001]. In the route name and milepost referencing method, each roadway is given a unique name and/or number, and the distance along the route from a specific origin is used to locate points along the route. The distance units are usually marked with signs placed along the route (e.g., mileposts) to determine the position of linear or point "events" or data collection points in the field. One of the problems associated with this method is that the locations of the signs do not always agree with the actual location of the mile referenced when measuring using a DMI.

However, because of the increased use of GIS, automated data collection equipment, and Global Positioning System (GPS), coordinate-based referencing methods are becoming popular. The most common coordinate systems are the longitude and latitude, state plane coordinate system, and universal transverse mercator. Although many agencies use linear referencing systems for their PMS data collection and storage [NCHRP, 2004], coordinate-based systems are also becoming popular.

The use of GPS has many advantages in terms of location accuracy and data integration potential; however, it also creates significant challenges regarding compatibility with historical data and interoperability with existing systems.

2.3.3 MANUAL FIELD DATA COLLECTION

The manual method is still being used by many agencies to collect survey data used to populate PMS database. Manual visual inspection is usually performed by one or two people either driving at a slow speed and stopping occasionally or walking through selected segments. These inspections can be performed depending on budget and level of detail in a proposed PIMS. Apparently, walking provides more accurate and more detailed data than driving, but it is more expensive and time-consuming. Generally, manual methods of asset data collection are expensive, often requiring labour intensive site surveys. Further, they create safety concerns and can sometimes cause disruption to traffic flows.

2.3.4 AUTOMATED PAVEMENT DATA COLLECTION

Many state agencies in the developed nations are using automated equipment to collect pavement condition data needed for pavement management. Inventory and centreline information are collected using multipurpose, highway data collection vans that incorporate several of the following technologies: GPS, image capturing using photographic and video (digital) cameras, gyroscopes to determine the longitudinal and transversal slopes, and laser sensors. Pavement condition data acquired include smoothness, surface distress, skid resistance, and structural capacity. Most state DOTs collect pavement smoothness, rut depth, and pavement surface texture using inertial laser-based profilers at the network level. The most common method for measuring pavement friction or skid resistance is the ASTM skid trailer [Gramling, 1994].

Structural capacity is measured in the U.S., mostly at the project level, using falling weight deflectometers (FWDs). However, a few states (e.g., Kansas and Texas) use FWD data at the network level.

One of the advanced methods of taking measurements on roads is through the use of highly accurate aerial photos, and street-level video of entire state highway system as executed by Pennsylvania Department of Transport [McGinnis, 2003]. Data capture through video, as utilized in the Philippines [Luz et al., 2003], facilitated the verification of existing data and could assist in the gathering of future data for identifying inventory features on or along a roadway. The video data also provided a historical record of visual features that can be used at a later date if needed.

2.3.5 NEW DEVELOPMENTS IN DATA COLLECTION TECHNOLOGIES

New technology developments have produced a methodology that can quickly inspect roads and streets by using automated inspection equipment such as, but not limited to, a set of video cameras, profiling devices, and laser sensors. Cline, et al. [2001] reported on three different technologies that are currently considered acceptable: (i) 35mm analogue continuous film, (ii) digital camera, and (iii) digital line scan imaging (see Plates 1- 4). Digital line scan imaging is the newest of the three technologies.

Cline, et al. [2001] described in their paper the response to the request by the Naval Pavement Centre of Expertise and supported by the Tri-Service Pavements Group, to investigate new technology of obtaining field data to increase safety and reduce labour requirements during the data collection for streets, roads, and parking lots. This new technology was tried and tested with the Micro PAVER system (an Engineering Management System) and compared to the standard process of manual surveys.

Digital line scan imaging, the newest of the three technologies, was used for the project. During the execution of the above-named project; for the automated Pavement Condition Index (PCI) survey, the data was collected in the field using cameras, profiling devices, and laser sensors, which are all part of the data collection vehicle. The data was then downloaded into a workstation located at the office. Frames were used for automated data collection in place of samples (see Figure 2.1).

Plate 1: Data Collection Vehicle for 35mm Analogue Continuous Film Technology

Plate 2: Data Collection Vehicle for Digital Camera Technology

Plate 3: Data Collection Vehicle for Digital Line Scan Imaging Technology

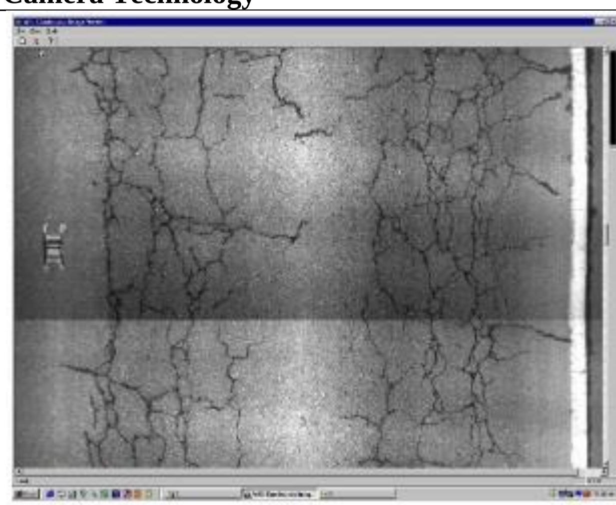


Plate 4: Continuous Image Viewer for Digital Camera Technology showing Pavement Distress

*Source***:** Cline et al., (2001)

The frames were reviewed by engineers/other qualified personnel, using a computer monitor to visually determine distress type, severity, and quantity. Distresses such as ruts were determined using data generated from a profiling device or laser sensor.

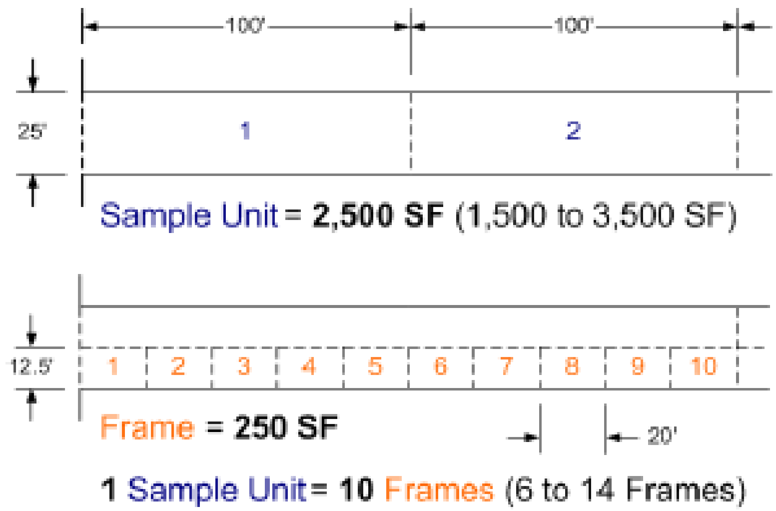


Figure 2.1: Asphalt Surfaced Roads Survey Using Frames
*Source***:** Cline et al., (2001)

Several pavement sections were marked so comparisons could be made by using the exact locations by both manual and automated techniques. Results indicate that in general, distress type and quantity are consistent between manual and automated techniques and the severity is somewhat inconsistent. However, severity appears to be typically lower by the automated system. Consistent distress type and quantity between techniques indicate that both field procedures produce similar results. The PCI values in Table 2.1 indicate both survey techniques, using the same pavement areas to determine PCI, result in similar values.

Based on the information obtained during the project evaluation, it was concluded that distress measurements taken manually or captured from automated images are consistent, PCI resulting from either manual or automated methodology is consistent, cost associated with both techniques are consistent, and the automated technique is safer and less labour intensive. The automated system has the ability to assess the condition of the pavement and use the resulting data to create and populate a Micro PAVER database. This can be conducted at the same cost or less than manual survey procedures and the surveys become less labour intensive and safe.

TABLE 2.1: COMPARISON OF MANUAL AND AUTOMATED DISTRESS DATA COLLECTION RESULTS

Pavement Section Surveyed	Manual PCI	Automated PCI
TARAWA 01	83	81
TARAWA 02	38	39
TARAWA 03	67	72
WASP 04	84	85
SINGLETON 06	59	61
TICONDEROGA 01	38	35

Source: Cline et al., (2001)

With the ability of Micro PAVER to accept data from frames, the report concluded that automated survey is just as feasible to integrate into a roadway pavement management system as is the manual survey. However, when automated survey techniques are to be used, the report [Cline, et al., 2001] warned that it is essential to contract with qualified specialists contractors.

2.3.6 BENEFITS OF AUTOMATED DATA COLLECTION

Kamnitzer David and McCarthy Tim [2000] reported that automated data collection technology, like GPS Encoded Video Technology, offers significant potential to reduce the cost of information collection and improve the accuracy and operational usefulness of the information.

Compared with traditional methods, the technology has the advantages of:

- speed;
- low cost, mainly due to low levels of labour requirements;
- little disruption to traffic flows;
- high levels of accuracy;
- record of information that was collected;
- ability to obtain all information about a particular route with a single survey; and
- ability to display information spatially (map), pictorially (stills and video) and as data (database application).

2.3.7 INTEGRATION OF GPS DATA INTO GIS-PIMS

GPS is currently being used for many applications, including pavement and asset management, vehicle tracking systems, and navigation systems. Compared with manual methods, GPS can help automate and speed GIS data processing and lower costs. It is also less labour intensive and may reduce digitizing and positional errors. Several studies have shown that the cost savings can exceed 50%. For these reasons, GPS is increasingly being used for facilities inventory and condition assessment. For example, the Virginia DOT (VDOT) has collected centreline information on 60,000 miles of roadway using GPS-equipped mapping vans outfitted with stereo cameras [Hovey, 2002].

The main advantages of using GPS for PIMS data collection include the possibility of determining the location accurately and using standard coordinate systems and reference datum. This makes it easy to import the information into a GIS and may reduce data collection costs, processing costs, and digitizing errors. The use of GPS during data collection may also speed up the data collection efforts, because the operators would not need to stop the vehicle and enter the location into the system. The main disadvantages include the need for specific equipment; potential problems with the signal owing to buildings or heavy foliage attenuating, reflecting, and/or blocking satellite signals; and potential compatibility problems with existing attribute data and maps.

2.4 PAVEMENT CONDITION RATING SYSTEMS

Based on measurements of roughness, surface distress, skid resistance and deflection, pavements can be assigned a score that reflects their overall condition. This score, sometimes called a pavement condition rating, quantifies a pavement's overall performance and can be used to help manage pavement networks. By carefully choosing the rating scale (called the condition index), pavement condition scores can be used to [WAPA, 2002]:

1. *Trigger treatment*. For instance, once a pavement's condition rating reaches a certain level, it can be scheduled for maintenance or rehabilitation.

2. *Determine the extent and cost of repair*. A pavement condition score is a numerical representation of a pavement's overall condition and can thus be used to estimate the extent of repair work and the likely cost.

3. *Determine a network condition index*. By combining pavement condition scores for an entire road network, a single score can be obtained that gives a general idea of the network condition as a whole.

4. *Allow equal comparison of different pavements*. Since a pavement condition score accounts for all types of pavement performance measures it can be used to compare two or more pavements with different problems on an equal footing.

A pavement condition index is simply the scale, or series of numbers, used to describe a pavement condition. Typical pavement condition indices may be based on a scale of 0 to 5 or perhaps 0 to 100; the higher the number, the better the pavement condition. The proper pavement condition index depends upon the objectives of the PIMS used to manage a particular pavement network. There are two major types of pavement condition indices, Present Serviceability Index (PSI) and Pavement Condition Index (PCI).

2.4.1 PRESENT SERVICEABILITY RATING (PSR) and PRESENT SERVICEABILITY INDEX (PSI)

The concept of serviceability was developed at the AASHO Road Test that was conducted in the late 1950s [Carey and Irick, 1960]. As part of that study, a panel of raters was driven over the various test sections and asked to rate the pavement using the following scale:

0-1 (Very poor); 1-2 (Poor); 2-3 (Fair); 3-4 (Good) and 4-5 (Very good).

The average rating of all of the raters, termed the Present Serviceability Rating (PSR), was an indication of how well the pavement was performing from a user's point of view. The PSR was used to track the performance of a pavement over time, and was used to indicate points in time when a pavement became too rough and was in need of rehabilitation. The PSR was used in the development of the AASHO pavement design procedure and remains an integral part of the current AASHTO procedures for both new design and for overlay design.

The PSI, which is a more objective assessment of the pavement surface condition than the PSR, and with values also ranging from 0 to 5, is a statistical regression of mechanical measurements from the surface of the pavement. The PSI may be computed using the following equations:

(a) Flexible Pavement:

$$PSI = 5.03 - 1.91\log(1 + SV) - 0.01\sqrt{(C + P)} - 1.38(R)^2$$

(b) Rigid Pavment:

$$PSI = 5.41 - 1.80\log(1 + SV) - 0.09\sqrt{(C + P)}$$

where

PSI = Present Serviceability Index

SV = the mean of the slope variance in the two wheel paths

C = a measure of cracking in the pavement surface

P = a measure of patching in the pavement surface

RD = a measure of rutting in the wheel path.

While the PSI concept is useful for determining when rehabilitation is required from a user's viewpoint, it should not serve as the only factor triggering the need for rehabilitation. The entire pavement must be thoroughly and completely examined in order to identify the causes of deterioration. For example, a pavement may be relatively smooth and still possess certain types of distress that indicate significant deterioration. A complete pavement evaluation, including an evaluation of a pavement's structural capability, is needed to accurately assess its condition.

2.4.2 PAVEMENT CONDITION INDEX (PCI)

The PCI is an objective and repeatable rating of pavement condition based on observable distress. PCI is defined as an index reflecting the composite effects of varying distress types, severity level, and extent upon the overall condition of pavement. PCI procedures for roads, parking lots, and airfield pavements have been developed [ASTM D 6433, 1999].

PCI values range from 0 to 100, which are defined as failed and excellent conditions, respectively. A PCI of 100 represents a pavement completely free of distress while a PCI of 0 corresponds to a pavement that has failed completely and can no longer be driven upon safely at the designed speed.

The PCI value is decreased by a cumulative deduct value score based upon the type, quantity, and severity level of distress and type of pavement. In terms of benefits and savings, network-level management tools such as PCI, help personnel develop rational budget requests and allocate optimal budget assignments.

Pavement Condition Ratings (PCRs) are associated with ranges of PCI. Table 2.2 shows the range of PCI values to which each rating corresponds. The scale used in the table is widely accepted by pavement engineers in the United States as well as internationally.

TABLE 2.2: PAVEMENT CONDITION RATINGS AND PAVEMENT CONDITION INDEX RANGES

Pavement Condition Rating (PCR)	Pavement Condition Index (PCI)
Excellent	86-100
Very Good	71-85
Good	56-70
Fair	41-55
Poor	26-40
Very Poor	11-25
Failed	0-10

Pavement condition rating data can be used to assess overall pavement condition, to identify pavements requiring maintenance and rehabilitation, to identify feasible maintenance and rehabilitation strategies, and to prioritize paving projects. Additionally, the results can be used to forecast the funds required to maintain a pavement network in serviceable condition.

2.5 DEVELOPMENT OF PAVEMENT PERFORMANCE MODELS

Performance is a general term for how pavements change their condition or serve their intended function with accumulating use. Pavement performance analysis consists of the development of mathematical models to determine and describe the past performance and predict future performance of family groups or individual pavements.

Pavement performance prediction models are some of the most important components of a PIMS. Capabilities of a PIMS are largely dependent on these models. Prediction models are used in the following activities [Smith, 1996]:

- To estimate future pavement conditions
- To assess the type and timing of maintenance and rehabilitation actions
- To optimize or prioritize maintenance and rehabilitation actions for single and multiple years
- To analyze the impact of maintenance and rehabilitation on the future condition
- To find out the life cycle cost
- To provide "feedback" to the pavement design process

Prediction models can predict a single pavement condition indicator, such as alligator cracking, roughness, etc., in terms of extent/severity or condition index (PCI), or an overall pavement condition index (combination of all distresses and ride quality), such as pavement serviceability

A prediction model can be developed by one of the following methods [Smith, 1996]:

- Empirical method
- Mechanistic method
- Mechanistic-empirical method
- Bayesian method

2.5.1 EMPIRICAL MODELS

Empirical models are constructed on the basis of the following statistical models using observed data and subjective data:

- Stochastic models, such as:
    - Linear regression analysis on single or multiple independent variables
    - Non-linear regression analysis on single or multiple independent variables
- Probabilistic models, such as:
    - Survivor curve
    - Markov model
    - Semi-Markov model

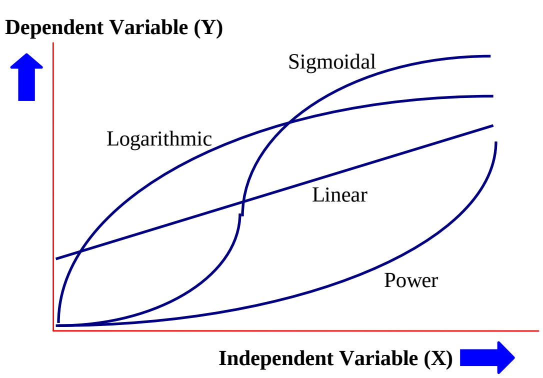


Figure 2.2: Typical Regression Curves

One of the most important steps in constructing an empirical model is the selection of an appropriate form; although, selection of relevant variables is also very important. There are various forms of regression models, such as, linear, power, sigmoidal (S-shaped), log values, etc., which are shown in Figure 2.2. Routine maintenance schedules, unrecorded corrective maintenance and preventive maintenance can alter the condition of pavement vis-à-vis rate of deterioration and therefore, these aspects must be considered in developing a deterioration model [Smith, 1996].

2.5.2 MECHANISTIC MODELS

Mechanistic models are developed on the basis of theory of mechanics. Mechanistic models are often developed using:

- Elastic layer theory
- Visco-elastic theory
- Fracture mechanics
- Finite element analysis

Mechanistic models are used to obtain primary responses such as stress, strain, deflection, etc., at critical points in a pavement structure under static or moving load condition on the basis of some theory on mechanics of material mentioned above.

Several computer programs have been developed for mechanistic analysis and design and some of them are itemized below:

- *BISAR* developed by Shell in 1973 considers both vertical and horizontal loads.
- The *DAMA* program developed by the Asphalt Institution in 1979 considers the pavement as nonlinear elastic layers.
- *ILLI-PAVE* developed by Raad and Figueroa in 1980 was based on finite element method.
- *VESYS IVB* developed by Jordahl and Rauhut in 1983 is based on visco-elastic theory.
- *ELSYM5* developed at the University of California, Berkeley in 1986 considers the pavement as an elastic layered system and can analyze up to five layers under multiple wheel load.
- The nonlinear finite element method was used in *MICH-PAVE* computer program developed at the Michigan State University in 1989.
- *KENLAYER* and *KENSLAB* computer programs developed by Huang for flexible and rigid pavements respectively can be applied to layered system, such as, linear elastic, nonlinear elastic or visco-elastic under single, dual, dual-tandem and dual-tridem wheels [Huang, (1993].

However, due to the requirement of large amount of computer time, storage and input, these programs are not used in PIMS. Moreover, the type of input data, such as, pavement material characteristics, environmental data, loading pattern, etc. required for mechanistic analysis are generally not available in PIMS.

2.5.3 MECHANISTIC-EMPIRICAL MODELS

Mechanistic-empirical models are developed by correlating a primary response predicted by a mechanistic model with a usage or environmental cumulative variable at a particular level of distress. Pavement condition data from mechanistic model is subsequently adjusted to fit observed performance using suitable statistical method. These models are generally not used in the network level PIMS because of large requirement of data. An example of mechanistic-empirical model is the AASHTO rigid pavement design equation which was developed from the road test data [AASHTO, 1986]. In AASHTO method, pavement condition can be predicted from pavement material properties, thickness, traffic and climate parameters. At present, most of the state agencies in the U.S.A. use ASSHTO model (1986) as performance models in the project level PMS.

2.5.4 BAYESIAN MODELS

Bayesian models are generally developed by combining observed data and expert experience using Bayesian regression techniques which are primarily based on a famous paper published by the Rev. Thomas Bayes (1702-1761). In Bayesian regression analysis, the regression parameters are considered random variables with associated probability distribution.

The main advantage of Bayesian model is that these models do not require large amount of data. Prediction equations can also be formulated exclusively from past experience. Probabilistic models predict a range of values of dependent variable with a probability distribution. Probabilistic models are generally used only in the network level pavement management systems while deterministic models may be used at both the network level and the project level.

2.5.5 SURVIVOR CURVES

The use of survivor curves in assessing pavement service life started in 1934. A survivor curve is defined by Winfrey as "the curve that shows the number of units of a given group which are surviving in service at given ages”. The ordinates to the curve give at any particular age the percentage (or the actual number) of the original number which are yet surviving in service. The abscissa is measured in years or other suitable service unit [Winfrey, 1987]. The number of units surviving is generally expressed in percentage. The area under the curve divided by 100 (if units are expressed in percentage) gives the average service life of the units. Survivor curve gives the probable life of units at any particular age.

Six different methods for developing survivor curves using retirement data are described by Winfrey [1987]. Retirement in the case of pavement survivor curves is defined by Winfrey as "the removal from service of a significant portion of a highway facility through abandonment or reconstruction to a different type". Pavement resurfacing, reconstruction, abandonment and transfer can be considered as retirement. Therefore, the retirement is a function of the policy used for pavement rehabilitation measure. An application of survivor curves for the determination of pavement service life is explained by Winfrey and Howell [1988].

2.5.6 MARKOV MODELS

Markov models use transition probability matrices. A transition probability matrix (TPM) is a collection of probabilities of pavement condition transitions from one level to another. In this method it is assumed that the future condition is a function of the present condition only and is not dependent on the past performance. Transition probabilities can be obtained by observing the performance of a large number of pavements under different rehabilitation action over a long period of time. Following Markovian chain method, the future pavement condition state vector, PCS(t), of the pavement at any stage, t, can be calculated from the initial condition state vector PCS(0) as:

$$PCS(1) = P_1 PCS(0)$$
$$PCS(2) = P_2 PCS(1) = P_2 P_1 PCS(0)$$
$$PCS(t) = P_t PCS(t-1) = P_t P_{t-1} \ldots P_1 PCS(0) \qquad (2.1)$$

where, P_t is the transition probability matrix at stage t and PCS(t) is the condition vector at stage t. PCS refers to the pavement condition states, such as serviceability index, pavement condition index, etc., suitably scaled for quantitative analysis. If a scale of 1-5 is used where 5 and 1 represent the best and the worst condition, respectively, PCS(2) which is the condition vector at stage 2 can be typically expressed as {0.4, 0.3, 0.2, 0.1, 0.0}, where the elements of the vector represent the percentage of pavement section in five condition state (1 to 5) for PCS level from 1 to 5. Generally stages are considered as series of consecutive periods of one year.

2.5.7 SEMI-MARKOV MODELS

Semi-Markov models are developed using available data and judgement/experience of the pavement experts. The main advantage of this type of model is the use of subjective inputs which reduce large requirement of field data. However, unlike Markov model, these models may predict future conditions from past conditions through transition probability matrices. "It is unique in seeking no cause-and-effect relationship but in simply estimating the rate of deterioration of the pavement" [Smith, 1996]. These models may be used at the project level.

A comparison of the models described is given in Table 2.3.

2.6 APPLICATION OF EXPERT SYSTEM TO PAVEMENT MANAGEMENT

An expert system is a sophisticated computer program that manipulates knowledge, facts, and reasoning in an attempt to solve problem efficiently in narrow problem area that would normally require the services of expensive human expert [Allez, et. al. 1988]. Using expert systems for various applications in transportation is now new [Ritchie, et. al. 1986, Hall et. al. 1987, Hendrickson, et. al. 1987 and Ritchie 1987]. According to Norlela et. al. [2009], the development of expert system (also known as knowledge-based system), has been among the most active research area in artificial intelligent during the last few decade. It was developed to simulate or reproduce intelligent problem solving behaviour in a computer program.

The goals of expert system are usually more ambitious than those of conventional computer program; they frequently perform not only as problem solvers but also as intelligent assistance and training aids. They have the capability to collect human know-how into a knowledge-based and apply this knowledge to reason through the solution of a problem without the need to reprogram its source code [Chang et.al. 2005]. Expert systems emulate human expertise and judgment through the use of symbolic logic and heuristics particular in problem area that requiring specialized knowledge, skill experience or judgment for determination of solution strategies and solutions. The advantages of this artificial expertise over the human expertise are that it is permanent, consistent, easy to transfer, easy to document, consistent and affordable, whereas human expertise is perishable, difficult to transfer, difficult to document, unpredictable and expensive [Kaplan, 1989].

The structure of an expert system consists of five major components: knowledge-base, inference engine, user interface, working memory, and knowledge acquisition [Haas et al. 1994]. The knowledge base consists of rules and facts that are captured from knowledge, opinion, and experiences of experts. The knowledge base defines the knowledge presentation scheme which determines the relationship between rules and facts.

TABLE 2.3: A COMPARISON OF PERFORMANCE MODELS

Models	Advantages	Disadvantages
Regression	• Microcomputer software packages are now widely available for analysis which makes modelling easy and less time consuming. • These models can be easily installed in a PMS. • Models take less time and storage to run.	• Needs large database for a better model. • Works only within the range of input data. • Faulty data sometimes get mixed up and induces poor prediction. Needs data censorship. • Selection of proper form is difficult and time taking.
Survivor Curve	• Comparatively easy to develop. • It is simpler as it gives only the probability of failure corresponding to pavement age.	• Considerable error may be expected if small group of units are used.
Markov	• Provides a convenient way to incorporate data feedback. • reflects performance trends regardless of non-linear trends	• No ready made software is available. • Past performance has no influence • It does not provide guidance on physical factors which contribute to change. • Needs large computer storage and time.
Semi-Markov	• Can be developed solely on subjective inputs. • Needs much less field data. • Provides a convenient way to incorporate data feedback. • Past performance can be used	• No ready made software is available. • Needs large computer storage and time.
Mechanistic	• Prediction is based on cause-and-effect relationship, hence gives the best result.	• Needs maximum computer power, storage and time. • Uses large number of variables (e.g. material properties, environment conditions, geometric elements, loading characteristics etc.). • Predicts only basic material responses
Mechanistic-empirical	• Primarily based on cause-and-effect relationship, hence its prediction is better. • Easy to work with the final empirical model. • Needs less computer power and time.	• Depends on field data for the development of empirical model. • Does not lend itself to subjective inputs. • Works within a fixed domain of independent variable. • Generally works with large number of input variables (material properties, environment conditions, geometric elements, etc.) which are often not available in a PMS.
Bayesian	• Can be developed from past experience and limited field data. • Simpler than Markov and Semi-Markov models. • Can be suitably enhanced using feedback data.	• May not consider mechanistic behaviour. • Improper judgement can lead to erroneous model.

Source: Smith (1996)

The inference engine contains a control structure that uses data provided by user and applies the knowledge in the knowledge base to obtain the solution for a particular problem. The roles of the inference engine involves selecting the rules from the knowledgebase, evaluating the selected rules, generating new facts, retrieving facts from the knowledge-base and the user, and finally generating the problem solution [Smadi 2000]. The user interface translates the information contained in the knowledge base and processed by the inference engine to a form that is comprehensible and useful to the user. In other word the user interface provides a friendly interface between the user and the system. The working memory resembles a database of conventional programs. It keeps track of the program status and contains a large amount of data for the given problem. Knowledge acquisition acts as an editor for entering the rules to the rule base, modifying existing rules, and saving the rules in the rule base in a form that can be used by inference engine [Townsend 1986].

2.7 PROFESSIONAL PIMS SOFTWARE

While cities with populations of less than 22,500 can easily function using a manually-operated simplified PIMS, agencies with bigger population and bigger road network to manage have to use sophisticated, computerized PIMS to effectively deal with the voluminous amount of generated data.

Nowadays, there are highly sophisticated professional PIMS software available commercially and which could be incorporated successfully with spatial analysis software (such as ArcView GIS) to perform all necessary PIMS functions. One of such popular professional PIMS software is Micro PAVER. The problem with using such professional PIMS software in Nigeria is the high level of sophistication and inability to supply many of the basic information required to populate such software for effectiveness. It is for these and other reasons why sophisticated models such as TRRL Road Investment and World Bank Highway Design and Maintenance Standard models have had little success in Nigeria.

However, there is record also of highway agencies successfully developing in-house customized computer software to carry out required PIMS functions. It is therefore believed that the PIMS developed in this research work would record more success when implemented in the country.

2.7.1 Micro PAVER® PAVEMENT MANAGEMENT SYSTEM

Micro PAVER (a professional PIMS software based on the PCI method) is a pavement management system beneficial for use by military installations, municipalities, airports, countries, and any other organization responsible for managing a pavement network. Some of its abilities are said to include allowing organizations easy access to pavement inventory and inspection information; providing accurate analysis of current and future conditions, providing for graphical presentations of reports through a link with GIS software, and allowing for optimization of pavement maintenance and rehabilitation (M&R), even with budget restraints [APWA, 2004].

As a measure of its success, Micro PAVER boasts of subscribers including cities, universities, consultants, airports, and others. One recent improvement in the latest Micro PAVER is the ability to use hand-held computers in the inspection process. Users can enter inspection data in the field and then later upload the information into the Micro PAVER database automatically. This eliminates the tedious manual entry of the information into the database days or weeks after the inspection was done.

2.7.2 DYNATEST PMS

Dynatest PMS is an internationally tested and proven system based on the Dynatest analytical/ empirical pavement analysis methodology. Dynatest PMS has been in operation since 1981, being used on the road systems of municipalities, towns, counties, motorway and State authorities in Europe, the United States and Africa [Dynatest®, 2005].

The Dynatest PMS makes use of performance models based on fundamental engineering principles. Reliable prediction of future pavement condition is based on actual, measured physical properties of the pavements. Condition data consists of structural data gathered with the Falling Weight Deflectometer (FWD) and functional data in terms of roughness and distress information collected with the Road Surface Profile (RSP). Skid data is collected with the Dynatest 6850H or Dynatest 1295.

2.7.3 TRRL ROAD INVESTMENT MODEL FOR DEVELOPING COUNTRIES (RTIM2)

The TRRL road investment model is designed as an aid to decision making in the roads sector in developing countries [Kerali, 2003]. It can be used to determine road construction and maintenance costs, and it evaluates benefits of reduced vehicle operating cost and time savings consequent upon improvement. The model simulates the performance of a road over time and traffic patterns. The effect on vehicle operating cost of changing conditions of the road surface is taken into account in the determination of costs and benefits.

Road deterioration is calculated as a function of the construction specification, maintenance policy, rainfall and traffic. Road geometry and road surface condition are used to predict the vehicles' speed, and fuel consumption. Parameters such as cost of lubricating oil, fuel, tyres, vehicle maintenance, depreciation, etc are then determined to give the total vehicle operating cost for that year. Road maintenance requirements are then determined from the condition of the road surface in conjunction with the maintenance policy specified by the user. These requirements are then used to calculate the maintenance cost.

2.7.4 THE WORLD BANK'S HIGHWAY DESIGN AND MAINTENANCE STANDARD MODEL (HDM-III)

This model is designed with the same objectives as RTIM2. The major differences are in the number of road links it evaluates simultaneously, the facility for endogenous comparison of alternatives and the inclusion of an Expenditure Budgeting model. The road deterioration and the road user cost relationships are also extensively researched over a wide range of conditions and thus more mechanistically and behaviourally based than empirically.

2.8 PAVEMENT CONDITION EVALUATION

The evaluation of the current condition or performance of the pavement condition depends on both functional and structural evaluation. Structural evaluation is based on structural capacity or structural adequacy of a pavement while functional evaluation is based on field measurements relating to the following characteristics: riding comfort or roughness, safety, surface distresses, and the potential for foreign object damage (FOD) to aircraft which is meant only for airport pavement management system (APMS) [Shahin 1982, Ritchie 1987, and Haas 1997]. The evaluation of these characteristics is then expressed in the form of a quality index. For riding comfort, the ride quality of a pavement is addressed through measurement of surface roughness. Its indicator is represented by Riding Comfort Index (RCI), Riding Comfort Rating (RCR), or International Roughness Index (IRI). Safety is measured through surface friction. Surface distress which reflects the visual assessment (type, severity, and quantity) of pavement surface condition is represented by Surface Distress Index (SDI), Distress Manifestation Index (DMI), or Pavement Condition Index (PCI).

For APMS, most aviation agencies estimate the condition of the pavement using PCI methodology [Michail and Patrick, 1998] that rate the pavement from 0 (failed) to 100 (excellent).

Structural capacity, represented by Structural Adequacy Index (SAI), reflects the ability of a pavement to support traffic without developing appreciable structural distress or in other word, the load carrying capacity of a pavement. The purpose of the structural evaluation is to determine the allowable load of a pavement, to predict the pavement future service life with respect to the traffic using it, and to assess the strength of the existing pavement [Witczek 1978].

2.9 VISUAL PAVEMENT CONDITION SURVEY IN NIGERIA

Visual pavement condition surveys are generally carried out on federal roads by the pavement evaluation unit of the Highways Planning and Design Department in the Federal Ministry of Transportation. The methodology currently used in the country is an adaptation of the Road Monitoring for Maintenance Management (damage catalogue for developing countries) by the World Bank [RTR, 1990]. With this method, distresses are visually assessed for carriageway, shoulder, drainage, culvert and bridges structures and rated using the Organization for Economic Co-operation and Development (OECD) rating.

Distresses measured for pavement include cracks (AASHO Classes I to III), deformation (base shear and rut depth), surface deterioration (ravelling), and pavement failure (potholes and patches). Survey is carried out for every one hundred (100) metres of the road. Based on the cumulative ratings of distresses measured for each 100m section, an overall OECD rating is computed.
The Mean, Standard Deviation and Coefficient of Variation (C.O.V) are automatically generated for each category of distress by the aid of a specially prepared Excel worksheet. In addition, the Excel program plots a graph of the OECD ratings against the road length. The ratings are categorized from 1 (excellent) to 5 (poor) (Appendix A1).

Notable among the perceived shortcomings of this system is its inability to generate appropriate M&R actions corresponding to the ratings. The need to survey every one hundred metres portion of a pavement makes the methodology cumbersome and time-consuming. In addition, this system does not deliver more accurate results.

2.10 ADOPTED METHODOLOGY FOR THIS RESEARCH WORK

The developed PIMS is customized computer software that incorporates knowledge-based Visual Basic Windows and MATLAB applications (see Appendix A2). The computational aspects of the system are implemented using the MATLAB programming language with jet engine-based access to database files in Microsoft Access (mdb) format. The results and generated reports are displayed in Visual Basic interface. The system is a completely interactive menu-driven application.

In line with widely accepted methodology for network-level PIMS, the system is designed to operate with manual visual condition survey of the pavements. Collated field distress data can be entered in and the system automatically carries out PCI procedure and generates PCI condition rating for the particular road section. The system thereafter recommends suggested appropriate maintenance and rehabilitation strategies. Provision is also made for the storage and display of photographs and video shots of distresses taken during the survey.

The pavement performance and deterioration modelling technique adopted is the first order probabilistic Marchov process. However, as a further improvement to the use of a single homogenous transition probability matrix used by Atume [1992] and Ezemenari [1999], a series of TPMs are formulated to take cognizance of the effects of traffic volume and age.

A digitized federal road network map was generated using ArcInfo/Map software and displays in VisualBasic interface. The approach adopted for PIMS-Thematic Map integration is the exportation of results from the PIMS, and subsequent display on the digitized federal road network map, through Microsoft Access. Spatial information on traffic, type of pavement rehabilitation, and pavement condition can be presented for the highway system in the form of different themes. Temporal information can be displayed based on user selection of a particular year.

CHAPTER THREE
DEVELOPMENT OF PCI-BASED PAVEMENT EVALUATION

3.1 GENERAL

Generally, Pavement Information and Management System (PIMS) contains three primary components [FHWA, 1993] - (1) data collection and management, (2) analyses and (3) updating.

1. Data collection and management - The components include:
   - *(i)* *Inventory:* An inventory of physical pavement features including the number of lanes, length, width, surface type, functional classification and shoulder information.
   - *(ii)* *History:* A history of project data and types of construction, reconstruction, rehabilitation and preventive maintenance.
   - *(iii)* *Condition Surve*ys: Condition surveys that include roughness on ride, pavement surface friction, rutting and distress, e.g. alligator cracking, potholes, etc.
   - *(iv)* *Traffic*: Traffic information including volumes, vehicle type (classification) and load data.
   - *(v)* *Database*: A database that links all data files related to the PIMS.

2. Analyses, at a frequency established by the coordinating Federal or State Highway Agency, consistent with its PIMS objectives. The components under analyses include:
   - *(i)* *Condition Analysis*: A pavement condition analysis that includes ride, distress, rutting and surface friction.
   - *(ii)* *Performance Analysis*: A pavement performance analysis that includes an estimate of present and predicted performance of specific pavement types and an estimate of remaining service life of all pavements on the network.
   - *(iii)* *Investment Analysis*: An investment analysis that includes:
     - *(a)* A network-level analysis that estimates total costs for present and projected conditions across the network.
     - *(b)* A project level analysis that determines investment strategies including a prioritized list of recommended candidate projects with recommended

preservation treatments that span single-year and multi-year periods using life-cycle cost analysis.

(c) Appropriate horizons, as determined by the coordinating agency, for these investment analyses.

(iv) *Engineering Analysis*: For appropriate sections, an engineering analysis that includes the evaluation of design, construction, rehabilitation, materials, mix designs and preventive maintenance as they relate to the performance of pavements.

3. Updating – The PIMS shall be evaluated annually, based on the highway agency's current policies, engineering criteria, practices, and experience, and updated as necessary.

These general basic components are further expatiated and compiled, by this researcher, as a flowchart in Figure 3.1.

3.2 OPERATIONAL FRAMEWORK OF THE DEVELOPED PIMS

The operational framework of the developed PIMS is fashioned to follow the general standard guidelines for pavement management system as shown in Figure 3.2. The first stage in the operation of a standard pavement management system would be the gathering of data where all necessary inventory and historic data are collected. This is usually followed by the evaluation of the pavement condition, after field condition data entries have been entered into the system. From the results of the condition evaluation, the condition rating of the pavement sections surveyed are computed, leading to selection of appropriate M&R actions and costs recommended for each section.

Thereafter, if desired, the performance and user costs modelling could be carried out to generate multiyear deterioration profile for a series of M&R intervention strategies. Many different types of reports could be generated based on the analyses performed and the inventory data entered. In addition, the system has the capability of displaying a series of network-level reports in charts and themes.

The proposed PIMS (see Figure 3.3) is configured to carry out successive broad tasks to achieve the desired goals of the system. The system is activated by double-clicking on the customized icon on the desktop. From the File menu, the Inventory/PCI module is accessed, from where inventory and distress data information can be entered sequentially.

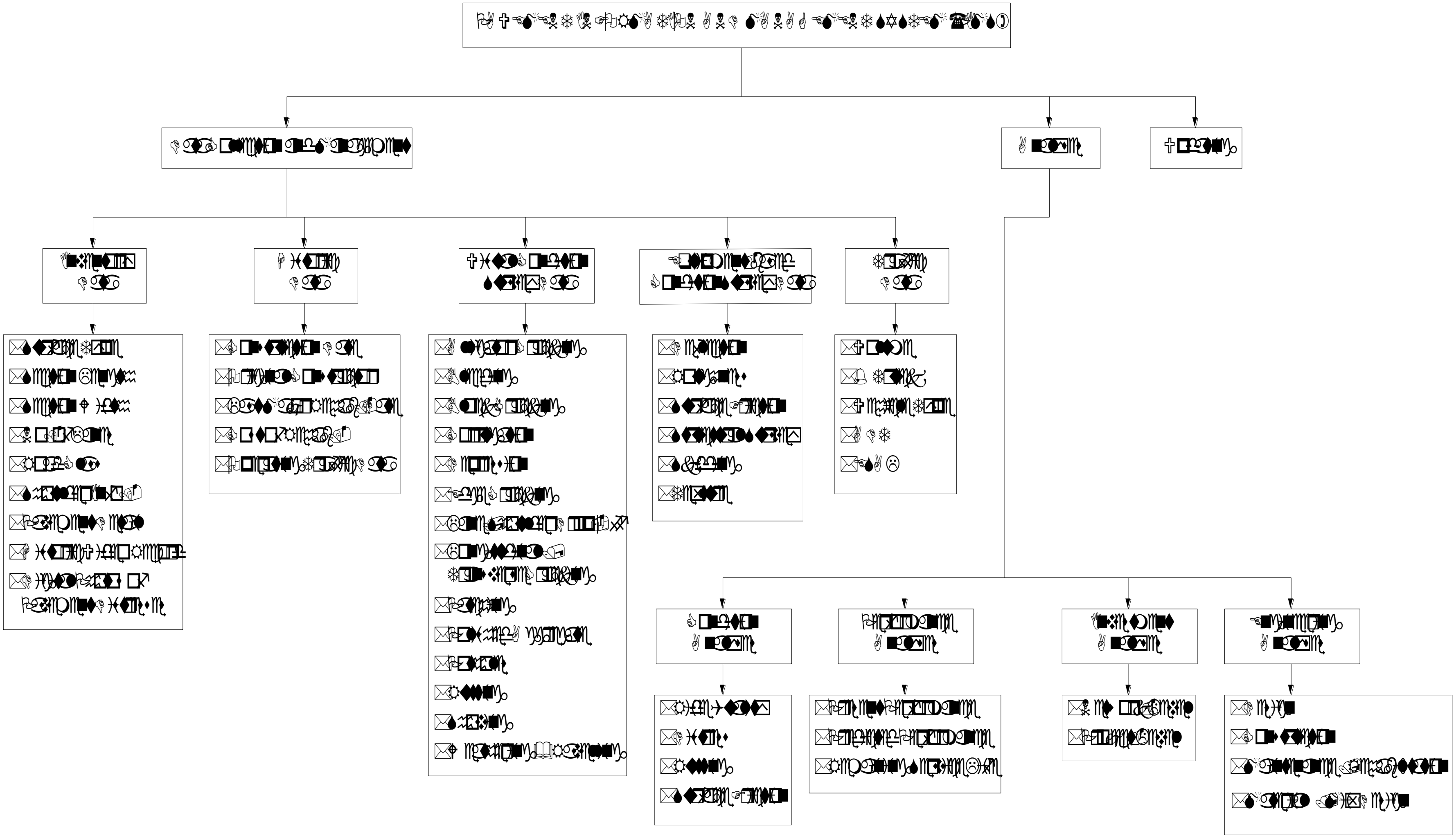


Figure 3.1: General Components of a Typical Pavement Information and Management System (Compiled)

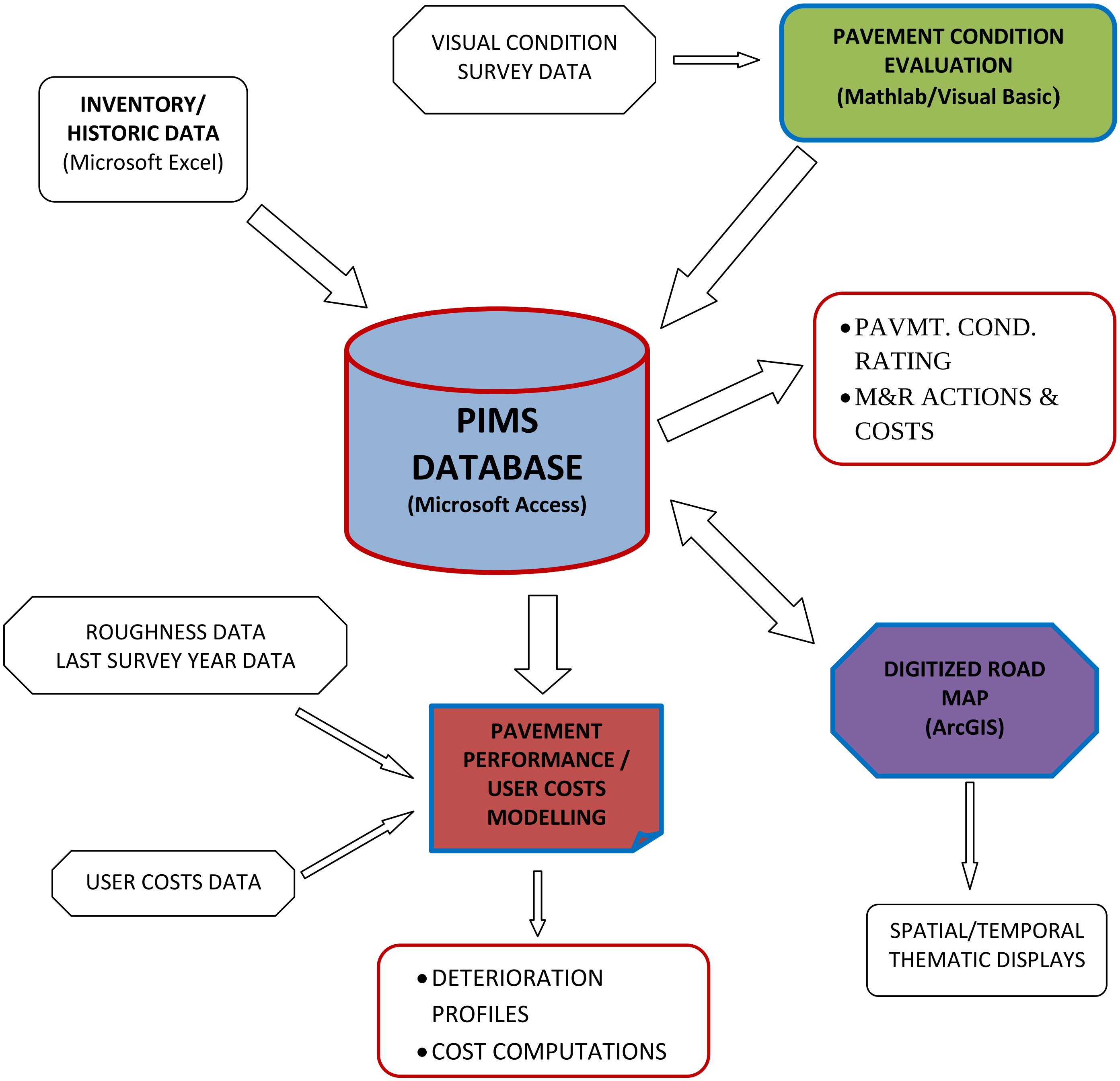


Figure 3.2: Operational Flowchart of the Developed PIMS

The condition rating (PCI) is calculated and the results can be displayed through the PCI Calculation Results interface. The condition reports module can be used to generate reports on the condition of the section or branch for a selected year of analysis. The prediction modelling module can be accessed next to carry out optional performance/user costs modelling and thereafter plot the deterioration profile based on the modelling.

The analyses module is designed to analyze and display historic and predicted results. Historic records of parameters such as PCI, ADT, M&R Actions and Costs can be plotted as charts. Thus, it will be possible to observe the trends of these parameters over time. The predicted analyses component can be used to predict and display future results of the selected parameters based on in-built internal calculations. Lastly, the Thematic Display menu can be used to switch to an interface where a digitized road map network is displayed and the results of the various analyses performed on the branches (at network-level) can also be reflected. Details of these steps are given in the foregoing sections.

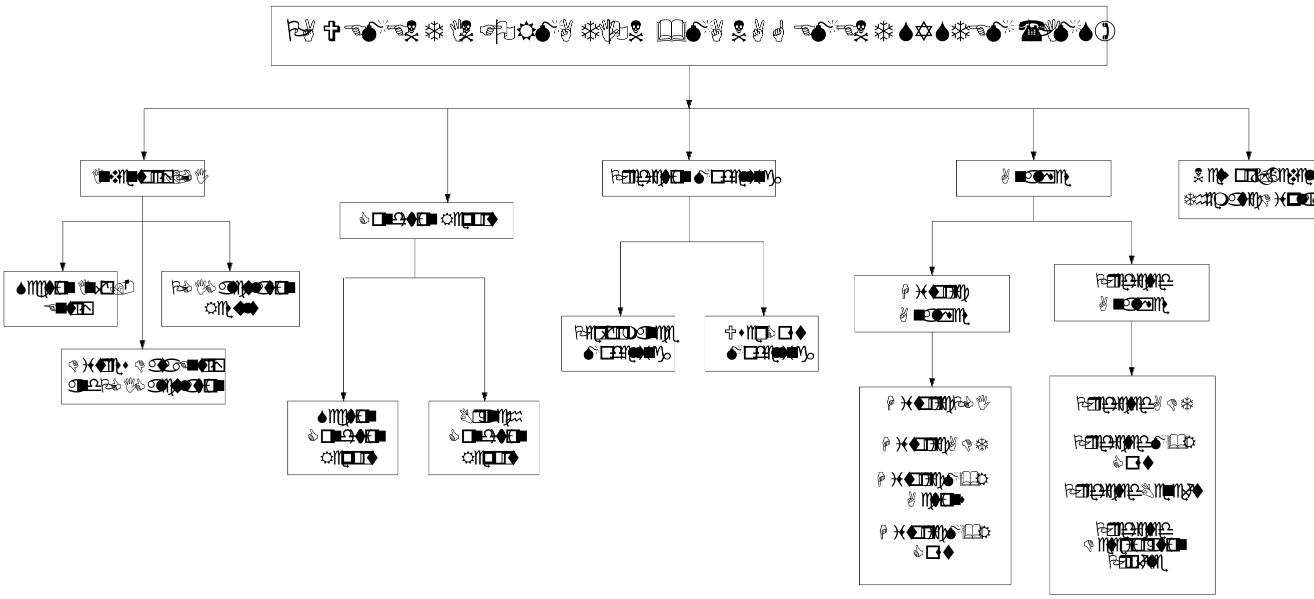


Figure 3.3: Broad Tasks in the Proposed PIMS

3.3 THE PAVEMENT MANAGEMENT PROCESS

The ad hoc approach to pavement management normally leads to gradual deterioration in the overall condition of the pavement network and thus increased backlog of unfunded major M&R requirement. This approach consists of the habitual application of selected few M&R alternatives (such as 37.5mm thick overlay) to pavement that are either in very poor condition or politically important. This is normally done regardless of the needs of the other pavements in the network.

A systematic approach to pavement management is needed to insure optimum return on investment. The following adopted approach has evolved over the past thirty years in the U.S. and consists of the following steps:

a) Network Identification

A network is a logical grouping of pavements for M&R management. The pavement network is broken into braches and sections. A branch is an easily identifiable entity with one use, e.g. a roadway, runway, taxiway, etc. The network selected for this research project work is the federal roads network. From the study of the available federal road maps, it was decided to group the pavements into a minimum of two networks. The first network (tagged 'FedRural') contains rural highways while the other network(s) would deal with highways and bridges in urban settings. The developed PIMS in this project work is for the 'FedRural' network. One major reason for this choice is the ability to suitably identify and represent the rural highways in the digitized map. Nearly all the rural highways have lengths clearly visible within the road network map unlike most of the urban highways.

b) Branch Identification

A branch is a readily identifiable part of the pavement network and has a distinct use. The branch naming convention implemented in this research work is the approved federal route numbering. A typical route number is 421(F.107), where 421 is the new route numbering and F.107 is the old numbering. Currently, there is no single comprehensive federal road network map (whether old or new) for the country, even in paper format. This can be attested to by the fact that neither the available old numbering federal road map nor the new numbering map fully contains all the routes listed in the Inventory of Federal Roads [FMWH, 1999].

Branch identification for this project work was performed using ArcGIS 9.0. This allowed for the creation of GIS shape files which are useful to display pavement data.

c) Section Identification

A branch does not always have consistent characteristics throughout its entire area or length. Consequently, branches are divided into smaller components called "sections" for managerial purposes. A section should be viewed as the smallest management unit when considering the application and selection of major M&R treatments. Each branch consists of at least one section, but may consist of more if pavement characteristics vary throughout the branch. Factors to consider when dividing braches into sections are [Shahin, 2005]: pavement structure, construction history, traffic, pavement rank (or functional classification), drainage facilities and shoulders, condition, and size. A brief description of the factors considered when dividing branches into sections are given viz:

(i) *Pavement Structure*

The structural composition (thickness and materials) should be consistent throughout the entire section. Construction records are a good source of this information but the records may be verified by taking a limited number of cores. A non-destructive deflection testing (NDT) program may also be performed to provide information regarding structural uniformity.

(ii) *Construction History*

Pavements constructed during different years, by different contractors, or using different techniques should be considered separate sections.

(iii) *Traffic*

The volume and load intensity of traffic should be consistent within each individual section. For highways with four or more lanes and two directions of traffic, a separate section may be defined for each direction, particularly if the highway is divided. A significant change in truck volume and weight should be a major consideration in section definition.

(iv) *Pavement Functional Classification (Rank)*

A change in rank normally reflects a change in traffic. If the rank changes along the branch length (for example, from trunk to secondary route), a section division should be made.

(v) *Drainage Facilities and Shoulders*

To the extent that drainage and shoulder provisions affect pavement performance, it is recommended that these provisions be consistent throughout a section.

(vi) *Condition*

Systematic changes in pavement condition should be considered when defining pavement sections. Condition is an important variable because it reflects many of the factors discussed above. Changes in distress types, quantities, or causes should be taken into consideration. Experience has shown that a combination of a distress condition index and NDT profiles leads to very successful section definitions.

(vii) Section Size

Section size can have a considerable impact on the economics of implementation. Defining very short sections, to ensure uniformity, requires a higher implementation effort and cost. The sections may also be too small to schedule individual M&R work productively. If they are too large, the characteristics may not be consistent across the entire area. This situation could result in non-uniform sections which in turn results in inefficient design and budget decisions.

3.4 BASIC ROAD BRANCH / SECTION INFORMATION

The division of the road branches into appropriate sections as highlighted above is capital intensive and can only be properly done in conjunction with the officials of the Federal Ministry of Transportation (Highways Division). Thus, the sectioning of all the road branches is outside the scope of this work. However, provisions for the eventual sectioning, when the PIMS takes off, have been made in the developed PIMS. In the interim, it is assumed that all the branches have only one section each. The exceptions are branches having more than one type of surfacing and those with enough information to properly section them.

1. Section Information Page

The branch/section code identifies the segment of the road network whose basic information is needed. The Section Information page (see Figure 3.4) is displayed when a user clicks on the PIMS icon located on the desktop. In this page, information about any road section within the federal roads network can be retrieved. Such information include inventory of physical pavement features such as number of lanes, length, width, surface type, road classification, and pavement materials information.

Other retrievable road information includes construction and maintenance history of any particular road section. Also on this page, new record can be created (for a road section newly added to the network); existing record for a road section can also be updated. Additionally, the total number of samples and exact number of samples to be surveyed for any road section are automatically calculated by the system based upon the user input of sample area, length and width of the road. Lastly, the operating traffic (ADT) and percentage of trucks data could also be added.

In order to validate the proper working of the form, all available information from the FMWH inventory [FMWH, 1999] for all the pavements in the network were input into the database. Such information included state, zone, route number (branch ID), road class (trunk route, secondary route, branch route and spur), branch length, carriageway width, type of surfacing (asphalt concrete, surface dressed and earth), sub-base/base materials and shoulder type (surfaced dressed, grassed or none). In all, a total of over 5000 units of inventory data for the federal roads have been entered.

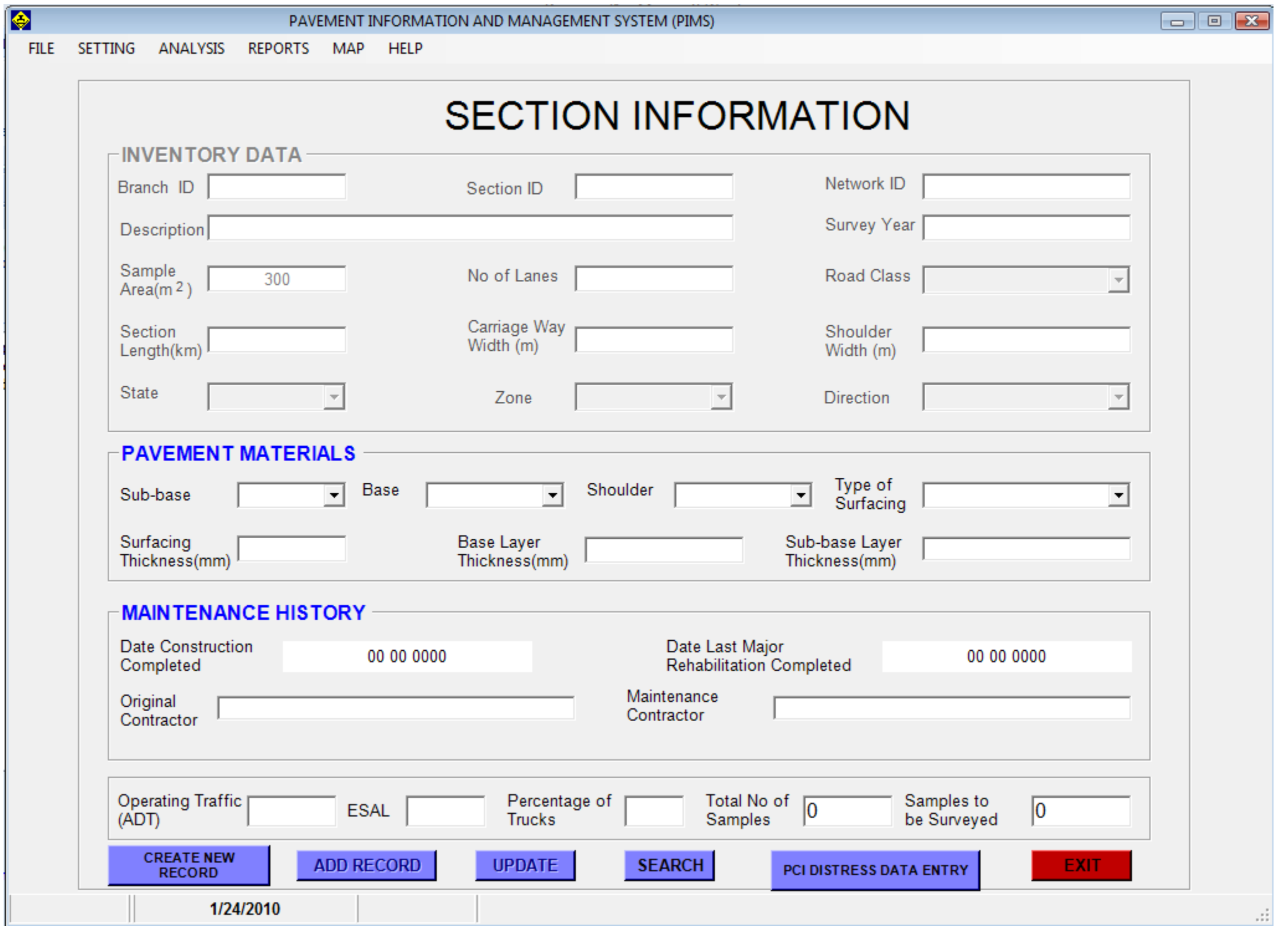


Figure 3.4: Created Road 'Section Information' Page of the PIMS

2. Loading an Existing Road Section Information

The first step to load up information for an existing road section is to click on the "Search" tab (located at the bottom part of the Section Information page). This displays the Search pop-up menu (Figure 3.5).

The "Search" pop-up menu allows a user to search for existing record for a road section within the federal road network. The user then has the option of searching for a road section using either the "Branch ID" or "Description" of the road. By typing just the first letter(s) of the description or first number(s) of the ID, and clicking the "Go" button, the list of roads that fall under such category displays. From the displayed list of roads, the user selects the desired one and click on the "Select" button to load up the stored information for the road section. The selected road [e.g. Enugu State Border-Umuahia-River State Border, and Branch ID of A70 (Dual) (A3)] loads up with the attached information (Figure 3.6).

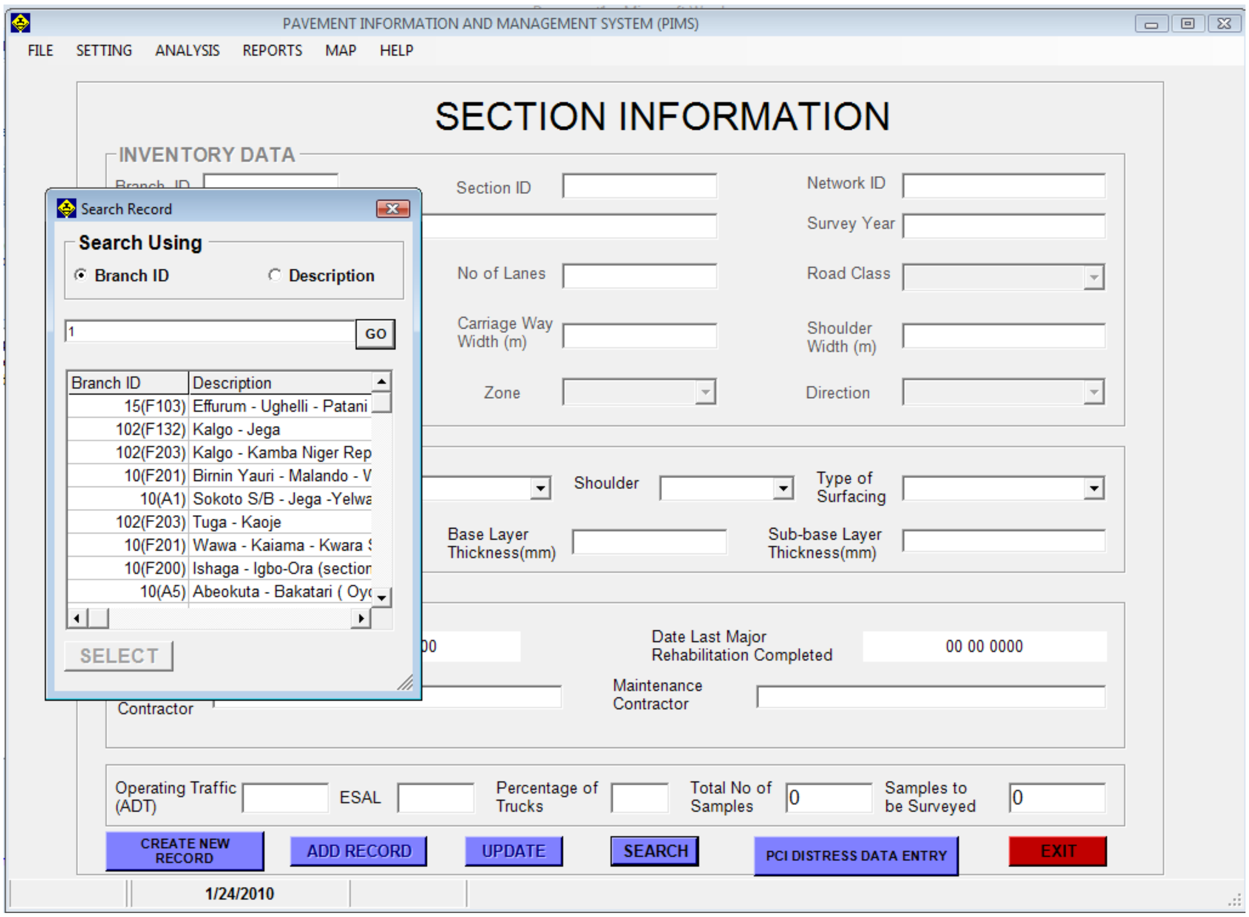


Figure 3.5: Searching for an Existing Road Section to Load into the PIMS

3. Notes on Displayed Data for a Selected Road Section

The following points should be noted in respect to the displayed data for any selected road section:

a) Data information will automatically be loaded up and displayed for a road section from the information stored in system's database.

b) It is possible to alter any existing data or update missing data. Thereafter, the "Update" tab is clicked to save the changes into the database.

c) For any road within the network, there are four possible road classifications available, namely: Trunk Route (TR), Branch Route (BR), Secondary Route (SE) and Spur (SP). The system allows for the classification of a road to be changed and updated accordingly.

d) Each road section in the network has been appropriately assigned (within the database), the state and zone to which it belongs. However, should this data change in the future, it is possible for a user to effect necessary changes by clicking on the down-pointing arrow and selecting a new data from the displayed list.

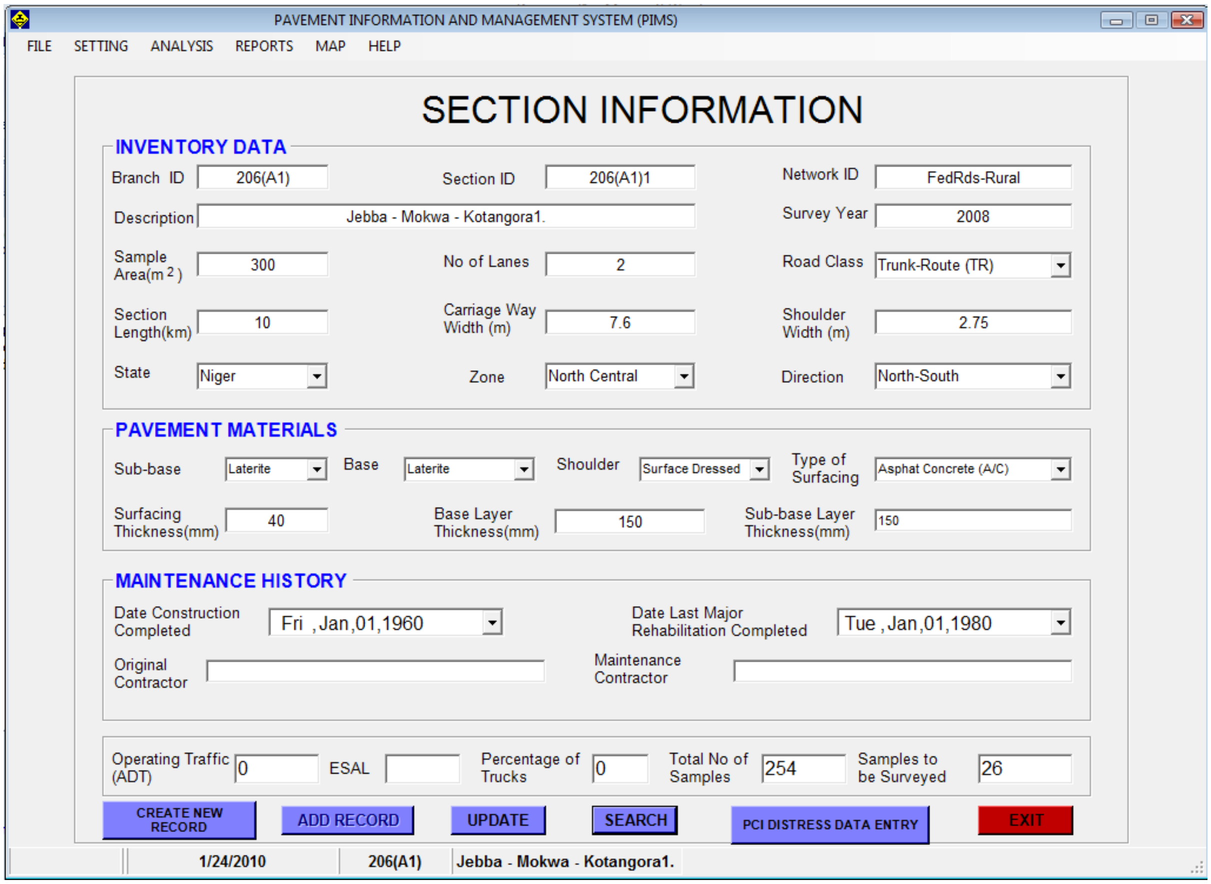


Figure 3.6: Display of Data Information for a Selected (Case-Study) Road Section

e) The available options for sub-base materials are: Laterite and Sand Fill.

f) The available options for base materials are: Crushed Stone, Laterite, Soil Cement, Sand/Bitumen.

g) The available options for shoulder materials are: Surfaced Dressed and Grass.

h) The available options for type of surfacing materials are: Asphalt Concrete (A/C), Surface Dressed (S/D), and Earth.

i) To update existing construction and maintenance dates or input afresh, the user clicks on the down-pointing arrow besides these options and a calendar displays. The year, month and day required can then be easily selected.

4. Dividing Pavement into Sample Units

A sample unit is a conveniently defined portion of a pavement section designated only for the purpose of pavement inspection. For asphalt surfaced roads, a sample unit is defined as an area 2500 $\pm$ 1000 sq. ft. (233 $\pm$ 93 m^2) [AASHTO, 2001]. As a result of the section's length, some sample units may have to be a different length than the others. Not all sample units are required to be the same size, but they do have to fit within the guidelines for recommended sample unit size to ensure an accurate PCI. It is suggested to adopt a default (starting) sample area of $300m^2$ but the suitability or otherwise will be determined after calculating the true area of the section (i.e. section length x carriageway width) and dividing by the starting sample area. If the last sample area falls outside the recommended range, then the starting sample area is adjusted (increased or reduced). It is also recommended that sample units be consistently numbered west to east, and south to north.

5. Determination of Sample Units to Be Surveyed

The first step in sampling is to determine the minimum number of sample units (n) that must be surveyed to obtain an adequate estimate of the section's PCI. In order to minimize the resources required for an inspection, a sampling plan was developed (for PAVER method) so that a reasonably accurate PCI could be estimated by inspecting only a limited number of the sample units in the pavement section.

For network-level decisions such as budget planning, a survey of a limited number of sample units per section is sufficient. If the objective is however to evaluate specific pavement sections for project development, a higher degree of sampling for a section may be required. For network-level inspection, the following guideline recommended for determining the number of sample units for inspection is shown in Table 3.1.

In this study and as typically recommended, a minimum sampling rate of 20% is proposed to be used for all sections, irrespective of the number of total sample units within the section.

For project-level inspection, the minimum number of sample units that must be surveyed can be determined from the following equation 3.1 [Shahin, 2005].

$$n = \frac{N s^2}{(e^2/4)(N-1) + s^2} \tag{3.1}$$

TABLE 3.1: NETWORK-LEVEL SAMPLING CRITERIA USED BY SOME AGENCIES

. Total Number of Samples in Section	Number of Samples for Inspection (n)
1 to 5	1
6 to 10	2
11 to 15	3
16 to 40	4
Over 50	10%

Source: Shahin, (2005)

where:

n = minimum number of sample units to be surveyed

N = total number of sample units in the pavement section

e = allowable error in the estimate of the section PCI

s = standard deviation of the PCI between sample units in the section

6. Selecting Sample Units to Inspect

It is recommended that the sample units to be inspected be spaced equally throughout the section, and that the first one is chosen at random. This technique, known as "systematic random" is described by the following three steps [Shahin, 2005]:

1. The sampling interval (*i*) is determined by $i = N/n$, where *N* equals the total number of available sample units and n equals the minimum number of sample units to be surveyed. The sampling interval (*i*) is rounded off to the smaller whole number (e.g., 3.6 is rounded to 3.0).
2. Random start(s) is/are selected at random between sample unit 1 and the sampling interval (*i*). For example, if $i = 3$, the random starts would be a number from 1 to 3.
3. The sample units to be surveyed are identified as s, s+i, s+2i, etc, where s=selected start. If the selected start is 3, and the sampling interval is 3, then the sample units to be surveyed are 3, 6, 9, 12, etc.

Example:

For a selected surveyed section of Jebba – Mokwa Road (length = 10km and width = 7.8m):

Total Number of Sample Units in Section (*N*) $= 260$ i.e. $\left(\frac{10{,}000\,x7.8}{300}\right)$

Minimum Number of Units to be Surveyed (*n*) = 10% of 260 = 26

Interval (i) = $\frac{N}{n}$ = $\frac{266}{26}$ = 10 = 10

Random Start (s) [from 1 to 10] = 3, say.

Thus, sample units to be surveyed are 3, 13, 23, 33, 43, etc.

7. Selecting Additional Sample Units

In following the above methods of sampling, it is possible that some sample units in exceptionally bad condition may not necessarily be included in the survey. To overcome this drawback, the inspection should identify any unusual sample units and inspect them as "additional" units. The calculation of the Section PCI when additional sample units are included is slightly altered to prevent extrapolation of the unusual conditions across the entire section. This procedure is discussed in Section 3.6.

3.5 PERFORMING THE VISUAL PAVEMENT CONDITION SURVEY

The key to a successful evaluation is to identify the different types and severity levels of pavement distresses for each type of pavement such that the actual condition of the pavement is defined and applied to calculate PCI. A visual condition survey of twelve (12) selected highway pavement sections (Table 3.2) was carried out in the month of August 2008 according to the procedure in ASTM D6433 [AASHTO, 2001]. The ASTM D6433 procedure for performing pavement condition survey is represented in Figure 3.7.

A description of each of the steps in the flowchart of Figure 3.7 is presented as follows:

1. Divide Pavement Section into Sample Units and Select Sample Units for Inspection

A determined number of sample units were surveyed by the team, which will represent the actual pavement condition of the entire section.

2. Type of Pavement and Inspection Method

Pavements in Nigeria are virtually flexible asphalt surfaced. Currently, the country has not got the technological capability to carry out automated condition survey and so, the only option available is the manual type.

TABLE 3.2: LIST OF HIGHWAY PAVEMENT SECTIONS SELECTED FOR VISUAL CONDITION SURVEY

S/No.	Description	Zone	Length ($x10^3$m) 'A'	Width (m) 'B'	Area (m2) 'AxB'	Total No. of Samples	No. Of Random Samples	No. Of Additional Samples
1.	Jebba – Mokwa-Kotangora Road (Setion I)	North Central	10.0	7.8	78.0	260	26	2
2.	Mokwa – Makera Road	North Central	52.2	7.8	407.2	1357	136	-
3.	Makera – Kasanga Road	North Central	34.0	11.2	380.8	1269	126	-
4.	Kasanga – Tegina Road	North Central	22.0	11.2	248.6	828	82	1
5.	Tegina – Ikerebodo Road	North Central	16.8	7.5	126.0	420	42	-
6.	Ikerebodo – Birnin Gwari Road	North Central	52.2	7.5	391.5	1305	130	-
7.	Egbe – Omu Aran Road	North Central	42	7.3	306.6	1022	102	1
8.	Ajaokuta – Adumu Road	North Central	38.8	10.2	395.7	1319	131	-
9.	Adumu – Ayingba Road	North Central	44.3	10.2	451.8	1506	150	-
10.	Maje – Suleja – Madalla Road	North Central	17.2	7.3	125.5	420	42	-
11.	Tegina – Zungeru Road	North Central	39	8.0	312.0	1040	104	-
12.	Zungeru – Minna Road	North Central	42.6	8.0	340.8	1136	113	-

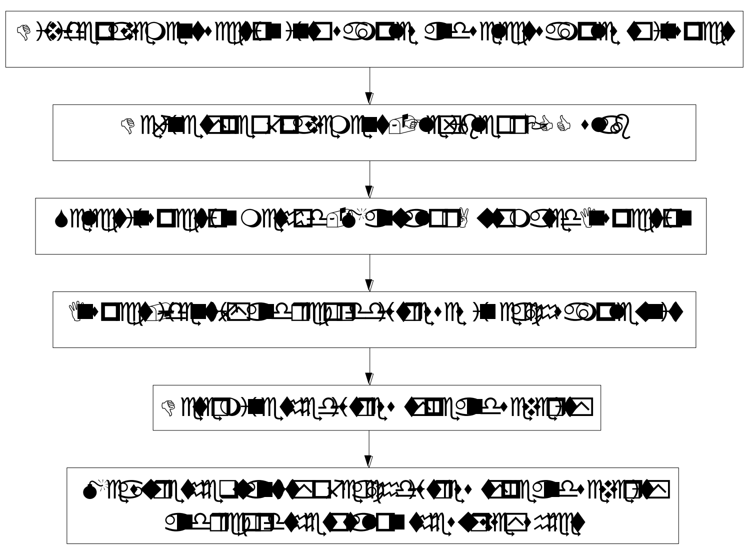


Figure 3.7: ASTM D6433 Flowchart for Performing Pavement Condition Survey

3. Inspect, Identify, Measure and Record Distresses

Each sample unit was walked upon. Depending on traffic control and safety condition, a sample unit adjacent to the one walked upon could also be surveyed. The team kept record sheets for each sample unit surveyed and recorded the distress type, severity and a measurement of quantity. A sample of created typical distress survey record sheet that was used is shown as Figure 3.8.

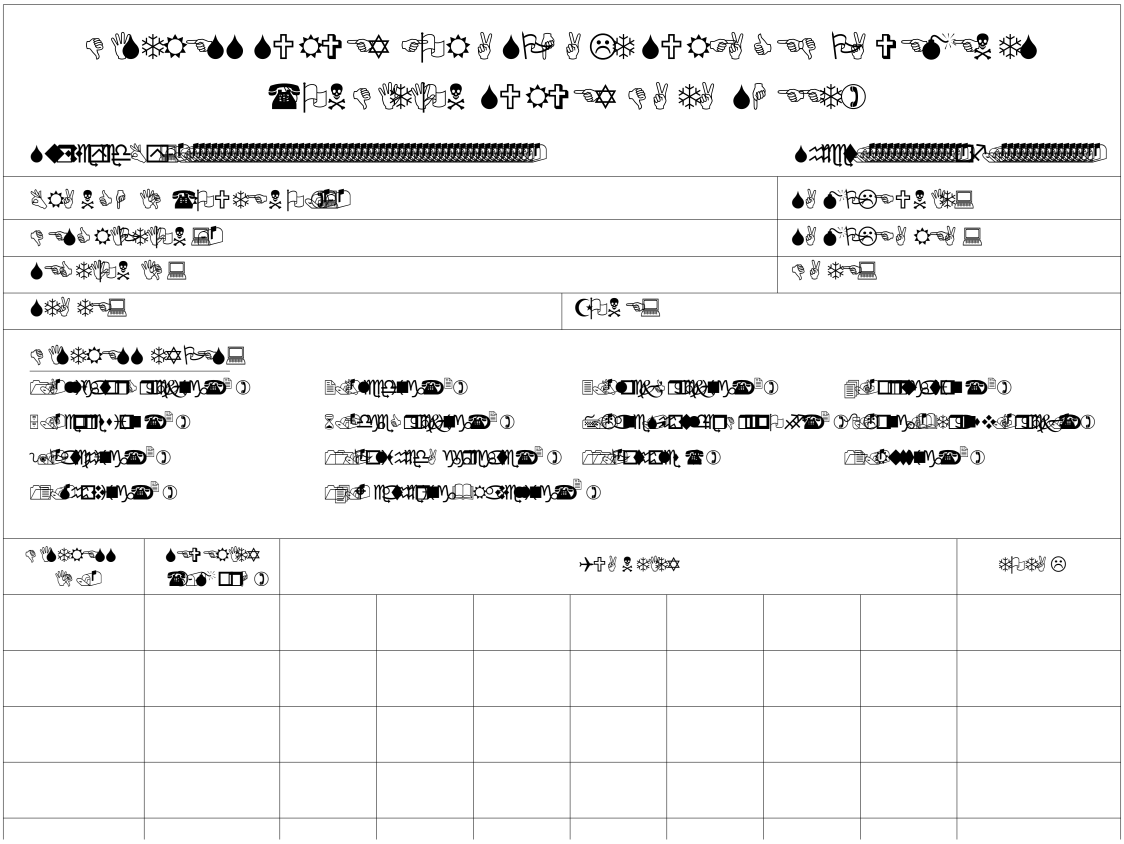


Figure 3.8: Created Sample of Condition Survey Data Sheet

Fourteen types of distresses are identified on asphalt surfaced pavements (Table 3.3 and Figure 3.8). The distress types, severities, measurement and repair options are shown in Appendix B.

Equipment needed for a manual distress survey is readily available and should include:

- Hand odometer (measuring wheel) or tape (at least 30 m) for measuring distances.
- Stringline or straightedge between 1 m and 2 m for measuring rut depth and/or drop-off.
- Small scale or ruler for fine measurements.
- Mid- to full-sized vehicle.
- Data sheets (and clipboard) for recording pavement distresses.
- Distress Identification Manual.
- Camera for photographing representative distress, and
- Hard hats and safety vests.

3.6 MANUAL DETERMINATION OF PCI VALUE

After the distress types, severity, and extent on the pavement are determined, the information may then be used to compute the deduct value of the concerned pavement. The following procedure is followed in the PCI method to obtain the PCI value of pavement sections as presented in the flowchart of Figure 3.9.

TABLE 3.3: ASPHALT CONCRETE SURFACED PAVEMENT DISTRESS TYPES

DISTRESS ID	DISTRESS TYPE	UNIT OF MEASURE	DEFINE SEVERITY LEVELS?
1	Alligator Cracking	Square metres (m^2)	Yes
2	Bleeding	Square metres (m^2)	Yes
3	Block Cracking	Square metres (m^2)	Yes
4	Corrugation	Square metres (m^2)	Yes
5	Depression	Square metres (m^2)	Yes
6	Edge Cracking	Square metres (m^2)	Yes
7	Lane/Shoulder Drop Off	Linear metre (m)	Yes
8	Longitudinal and Transverse Cracking	Linear metre (m)	Yes
9	Patching	Square metres (m^2)	Yes
10	Polished Aggregate	Square metres (m^2)	No
11	Potholes	Number (N)	Yes
12	Rutting	Square metres (m^2)	Yes
13	Shoving	Square metres (m^2)	Yes
14	Weathering and Ravelling	Square metres (m^2)	Yes

Source: AASHTO (2001)

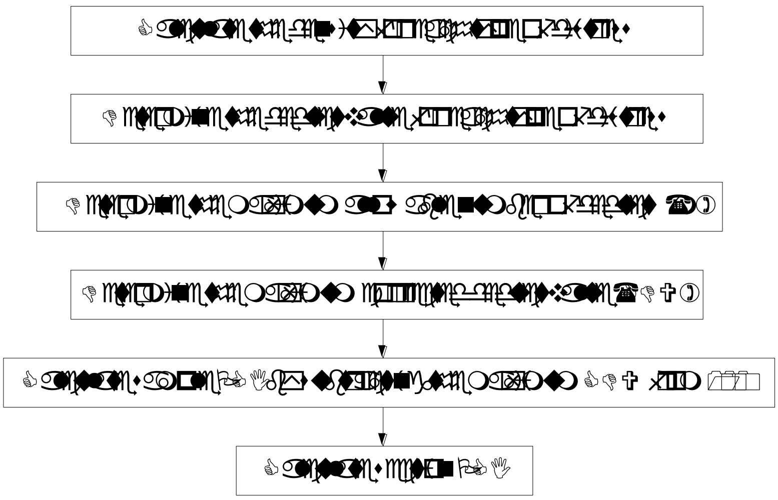


Figure 3.9: Flowchart of the Procedure to Calculate Section PCI (Compiled)

A description of each of the steps in the flowchart is presented as follows:

1. Calculate the Density for Each Distress Type

For asphalt concrete surfaced pavements, the total quantity of each distress type at each severity level is added up. The total quantity of each distress type at each severity level is divided by the total area of the sample unit and multiplied by 100 to obtain the percent density of each distress type and severity.

$$Density = \frac{Amount\ of\ Distress}{Area\ of\ Sample\ Unit}\ x\,100\ \text{[Expressed as \%]} \tag{3.2}$$

2. Determine Deduct Value for Each Type of Distress

The deduct value for each distress type and severity level combination are obtained from the distress deduct value curves as produced in ASTM D6344 and reproduced as Appendix C.

3. Determine the Maximum Allowable Number of Deducts (*m*)

If only one individual deduct value (or none) is > 2 (for flexible pavements), the total deduct value is used in place of the maximum corrected deduct value (CDV) in Step 4 and the PCI computation is completed; otherwise, the following steps should be followed.

(i) List the individual deduct values in descending order.

(ii) Determine the allowable number of deducts, *m*, using the following formula:

$$m_i = 1 + (9/98)(100 - HDV_i) \tag{3.3}$$

where:

m_i = allowable number of deducts, including fractions, for sample unit *i*.

HDVi = highest individual deduct value for sample unit *i*.

(iii) Reduce the number of individual deduct values to *m*, including the fractional part. If fewer than *m* deduct values are available, then all of the deduct values are used.

4. Determine the Maximum Corrected Deduct Value (CDV)

The maximum CDV is determined iteratively as follows:

(i) Determine the number of deducts with a value > 2 (q).

(ii) Determine total deduct value (TDV) by adding all individual deduct values.

(iii) Determine the CDV from q and TDV by looking up the Correction Curve for asphalt surfaced pavements (see Appendix D).

(iv) Reduce to 2.0 the smallest individual deduct value that is > 2.0. Repeat steps (i) through (iii) until q is equal to 1.

(v) The maximum CDV is the largest of the CDVs determined.

5. Calculate Sample PCI: This is calculated by subtracting the maximum CDV from 100.

6. Calculate Section PCI: If all surveyed sample units are equal in size, the PCI of the section is determined by averaging the PCIs of the sample units inspected. If the inspected sample units are not equal in size, area weighted averaging should be used, given by the equation [Shahin, 2005]:

$$PCI_S = PCI_r = \frac{\sum_{i=1}^{R} PCI_{ri} A_{ri}}{\sum_{i=1}^{R} A_{ri}} \tag{3.4}$$

where

PCI_s = PCI of pavement section

PCI_r = area weighted average PCI of random (or representative) sample units

PCI_{ri} = PCI of random sample unit i

A_{ri} = area of the random sample unit i

R = total number of random sample units

If additional sample units are inspected, in addition to the random or representative units, the section PCI is computed as follows [Shahin, 2005]:

$$PCI_a = \frac{\sum_{i=1}^{A} (PCI_{ai} A_{ai})}{\sum_{i=1}^{A} A_{ai}} \tag{3.5}$$

$$PCI_s = \frac{PCI_r \left[A_s - \sum_{i=1}^{A} A_{ai} \right] + PCI_a \sum_{i=1}^{A} A_{ai}}{A_s} \tag{3.6}$$

where

PCI_a = area weighted average PCI of additional sample units

PCI_{ai} = PCI of additional sample unit number i

A_{ai} = area of additional sample unit i

A_s = total section area

A = total number of additional sample units

3.7 PCI Calculation for the Selected Surveyed Road Sections

The preceding procedure was used to manually calculate the PCI for all the surveyed samples for Jebba – Mokwa - Kotangora (Section I) road. Following the PCI procedure, twenty six (26) representative samples and two additional samples were surveyed. The section PCI was then generated from the sample PCI results. The summary calculations for the entire sample PCI are provided in Appendix E1. Moreover, the developed PIMS was also utilized to calculate the sample and section PCIs.

In addition, similar computations were carried out for the remaining eleven (11) road sections that were surveyed (see Table 3.2). The results of both manual and automated computations are displayed and analyzed in chapter four.

3.8 AUTOMATED DISTRESS DATA ENTRY AND PCI CALCULATION

The surveyed Jebba – Mokwa – Kotangora road (Section I) is about 10km long and carriageway width of 7.8m, giving a total area of 73,000m^2, a total of 267 samples and about 26 samples to survey (at network level). As can be clearly seen from the preceding sections, the process of calculating the numerous sample PCIs for each one of such road sections is tedious, time-consuming and highly prone to human errors.

As a way of overcoming tedious, time-consuming and highly prone to human errors limitations in manual computations, the whole procedure of calculating the PCI of any road pavement section has been automated using the MATLAB and Visual Basic software programs. The flowchart for the automatic PCI distress computation is given in Figure 3.10 while the automated procedure is demonstrated for the surveyed Jebba – Mokwa – Kotangora Road (Section I).

A. Setting Current Cost Values for the M&R Options

After loading the data for a particular road section in the Section Information page, and prior to moving to the PCI analysis section, it is desirable to input the current costs (per kilometre) for the various maintenance and rehabilitation activities.

The user selects the "SETTING" menu option from the menu toolbar. The "SETTING…" dialogue box displays (Figure 3.11). By clicking on the "Edit" button, the user is allowed to input current values for the various M&R options. Thereafter, the "Save" button is clicked to save the input. (**N.B**.: The current default rates provided are based on year 2008 average going rates obtained from Lagos State and Federal Ministries of Transportation).

B. PCI Distress Data Form

While still on the Section Information page, and having entered the current M&R costs, the user clicks on the "PCI Distress Data Entry" button (lower right corner) to load the PCI Distress Data Form (Figure 3.12). The upper part of the form contains information for the selected road section, and this information is automatically loaded up, if available, from the database.

The lower part of the PCI Distress Data Form allows the user to input the survey data captured for the various samples taken from site. The sample area, sample unit number, sample type, distress type, distress severity and quantity are the necessary user input. The user selects the distress type first, followed by the distress severity and then input the distress quantity for every sample of road surveyed. The information is transferred from the site survey sheets.

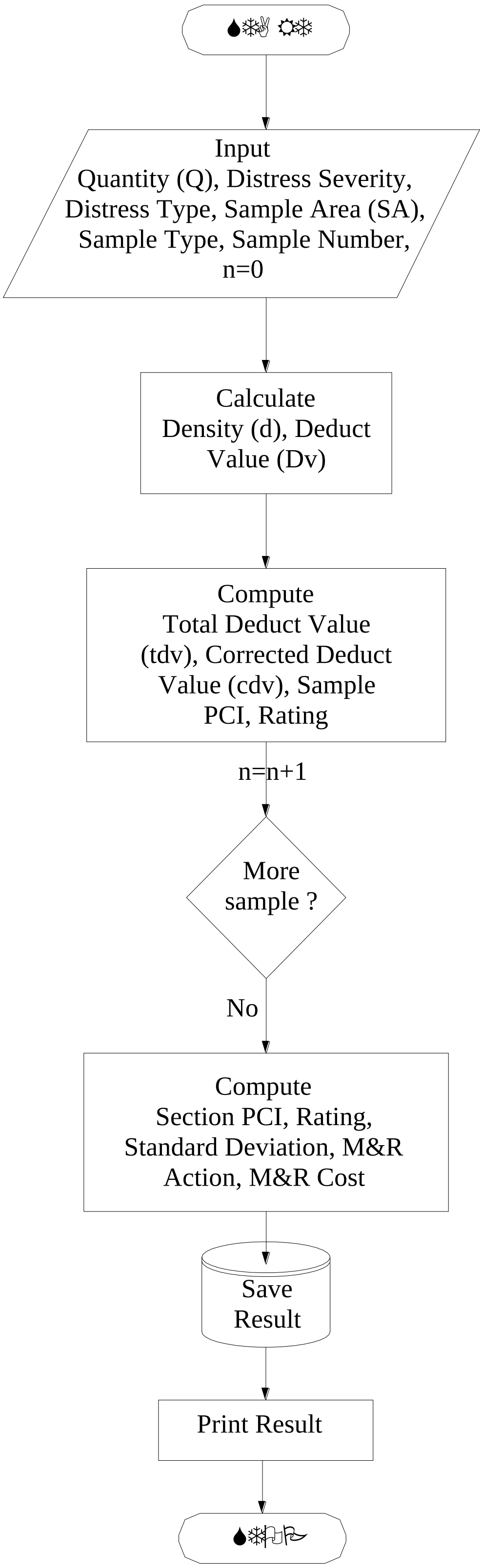


Figure 3.10: Flowchart for Automated PCI Computation

After all the distress data for a sample have been entered, the user clicks on "Sample Computation" to perform the analysis. Immediately, the Total Deduct Value (TDV), Corrected Deduct Value (CDV), Sample PCI value and sample rating are generated and displayed.

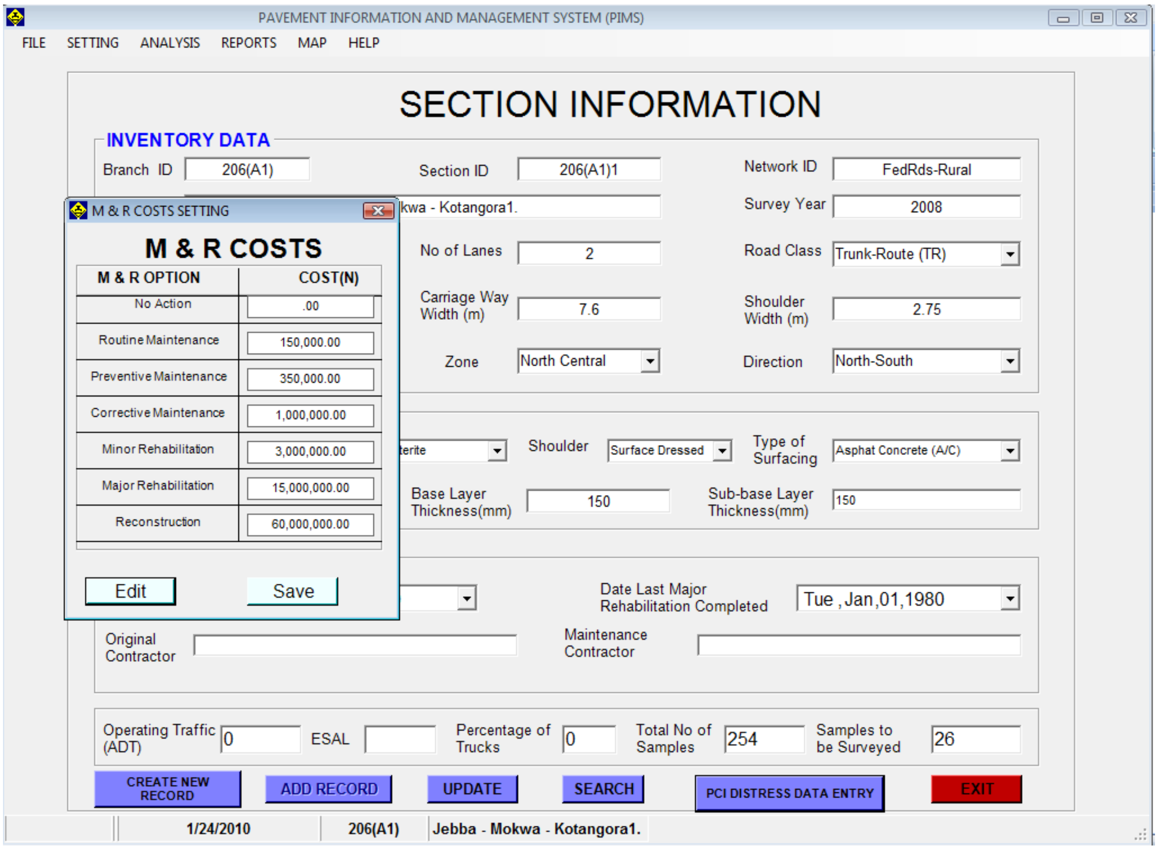


Figure 3.11: Entering Current Values for the M&R Options

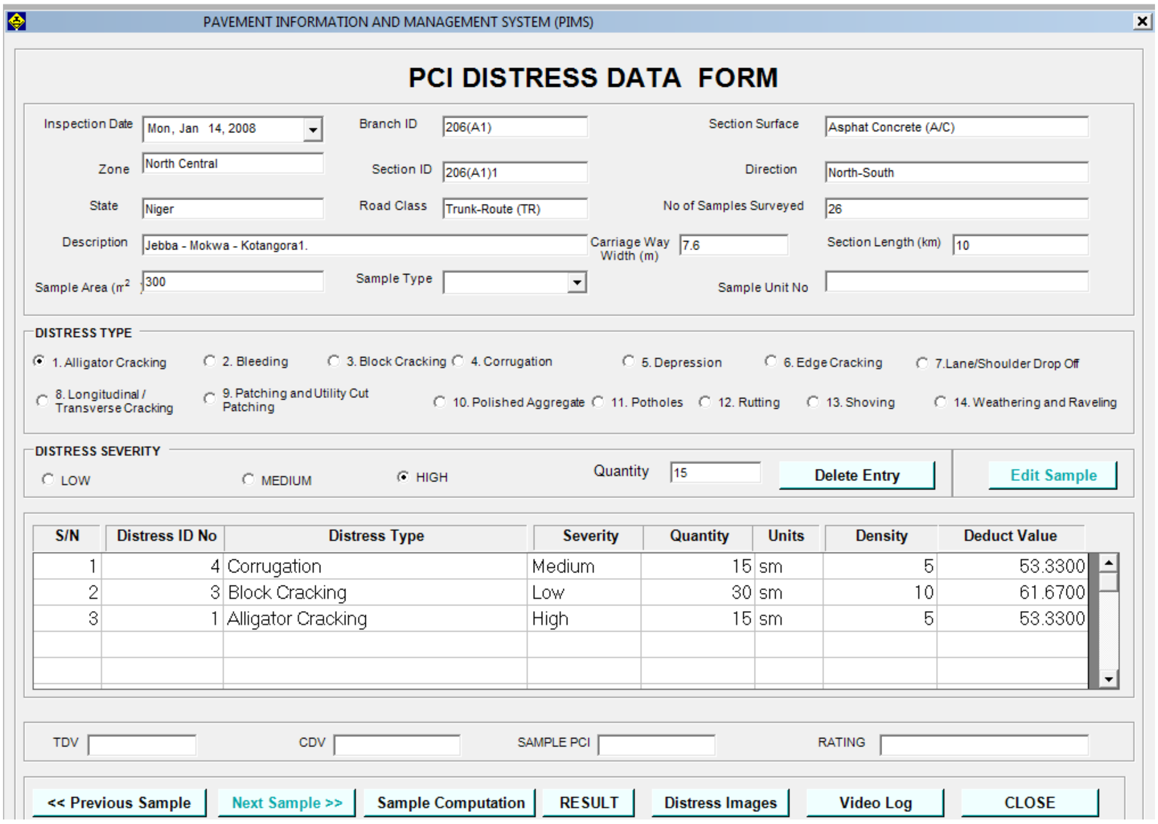


Figure 3.12: PCI Distress Data Form Interface

C. Other Operations within the PCI Distress Data Form Interface

Some other operations that could be carried out within the PCI Distress Data Form interface include:

Next Sample: This button allows the user to proceed to the next sample until all samples have been treated.

Previous Sample: This button gives the user the chance to navigate to previous samples to view and/or effect corrections.

Edit Sample: By clicking on this button, the user has the flexibility to edit data input previously entered.

Result button: This button displays the final results for all samples keyed in. It opens the result page (see chapter four).

Distress Image/Video Log buttons: Selecting either of these buttons opens a page where images and video log of distresses captured on site can be viewed (see chapter four).

3.9 GENERATING STRATEGIES FOR M&R ACTIONS

A comprehensive approach to pavement management requires the development and use of maintenance, rehabilitation, and reconstruction strategies, in order to effectively maintain the roadway network. These M&R strategies, when combined with specific road condition information such as pavement condition survey, pavement riding quality, and functional classification, lead to specific M&R actions. There are five basic strategies used by most government agencies for M&R actions, viz:

- **Routine maintenance** "consists of work that is planned and performed on a routine basis to maintain and preserve the condition of the highway system or to respond to specific conditions and events that restore the highway system to an adequate level of service" [AASHTO, 1998]. Examples of pavement-related routine maintenance activities include cleaning of roadside ditches and structures, maintenance of pavement markings and crack filling, pothole patching and isolated overlays. Crack filling is another routine maintenance activity which consists of placing a generally, bituminous material into "non-working" cracks to substantially reduce water infiltration and reinforce adjacent top-down cracks. Funds should be generated for routine maintenance each year. This work is normally anticipated within a budget cycle, but its location and timing may not be known in advance.

- **Preventive maintenance** is "a planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system (without significantly increasing the structural capacity)" [AASHTO, 1997]. While corrective maintenance activities are generally reactive, preventive maintenance is proactive, and consists of any activity that is intended to preserve or extend the service life of a pavement until a major rehabilitation or complete reconstruction is required.

  Preventive maintenance is intended to maintain the durability and flexibility of the pavement. It <u>does not</u> increase the structural strength/capacity, so is generally limited to pavement in good structural condition still having significant remaining service life. Preventive maintenance should be programmed systematically into the budget.

- **Corrective maintenance** is performed in response to the development of a deficiency or deficiencies that negatively impact the safe, efficient operations of the facility and future integrity of the pavement section. Corrective maintenance activities are generally reactive, not proactive, and performed to restore a pavement to an acceptable level of service due to unforeseen conditions. It is applicable when the pavement condition has deteriorated to the point that routine and preventive maintenance is no longer cost-effective but there is no need of major rehabilitation.
- **Rehabilitation:** As the pavement condition deteriorates, there comes a point when maintenance activities are no longer cost-effective and rehabilitation is required. Rehabilitation projects "extend the life of existing pavement structures either by restoring existing structural capacity through the elimination of age-related, environmental cracking of embrittled pavement surface or by increasing pavement thickness to strengthen existing pavement sections to accommodate existing or projected traffic loading conditions" [AASHTO, 1997].

- **Reconstruction** consists of the total removal of the existing pavement structure, reworking or improving the subgrade soil, re-compacting the subgrade soil, and placement of a pavement structure with new and/or recycled materials. Reconstruction may be done in those cases where the roadbed foundation or bridge condition has failed, or when improvements in alignment, drainage, or widening have become necessary, or maintenance is not cost-effective. In such cases, a full reconstruction or replacement is undertaken.

In practice, the strategy which should be applied can be decided based on evaluated PCI of the pavement within a roadway network. Without any maintenance action, the pavement performance, indicated by PCI, decreases every year. The range of PCI values associated with each level of service has been suggested so that the need for maintenances, and type of need can be then determined based upon PCI value only. The range for each level of service and types of needed maintenance actions are provided in Figure 3.15. Definitions describing each level of service [Misra, et al., 2003] are as follows:

- **Level of Service A:** A pavement is in relatively excellent condition. Pavement may have localized deterioration and low-severity hair cracking (Plate 5). It needs routine maintenance to arrest early signs of deterioration and to extend the pavement life. Recommended PCI range is 85-95. A pavement with PCI value above 95 needs no maintenance.

- **Level of Service B:** A pavement is in very good condition. It needs preventive maintenance to arrest early signs of deterioration and to prevent the development of more serious pavement problems. Recommended PCI range is 71-85.

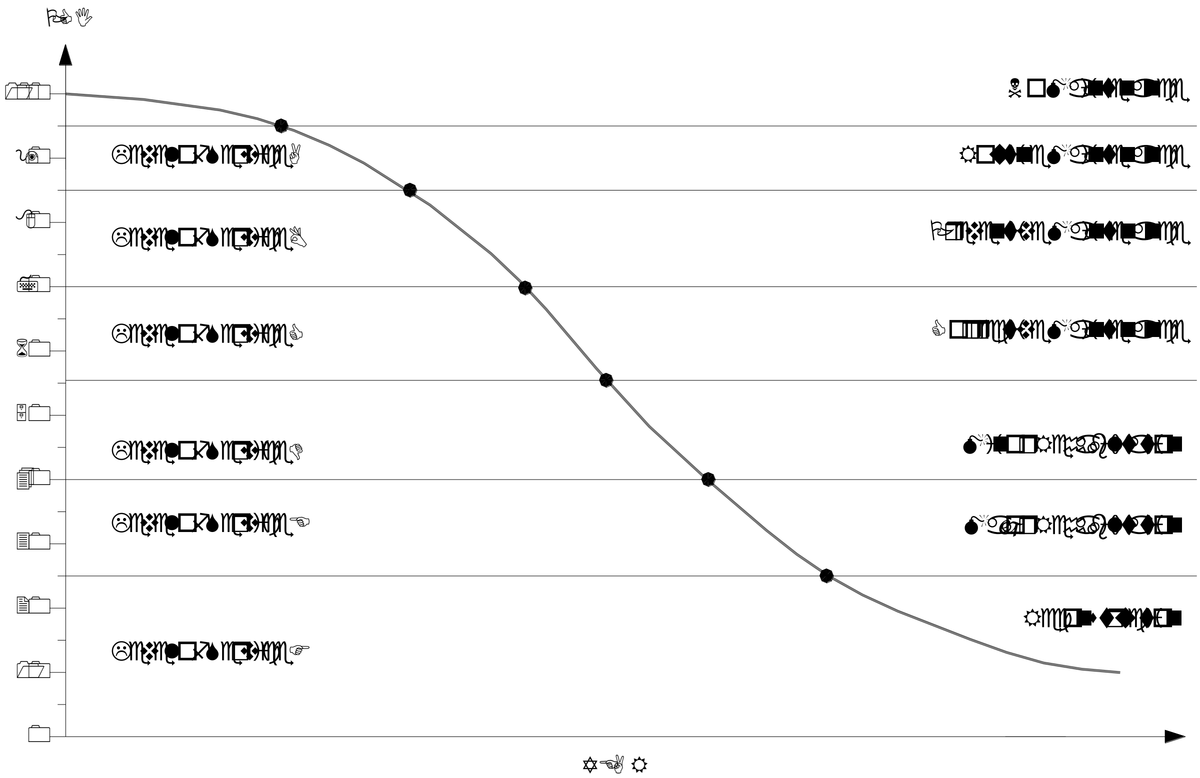


Figure 3.13: Maintenance Activity and Time for Each Level of Service Based on PCI
Source: Adapted from Misra, et al. (2003)

- **Level of Service C:** A pavement is in somewhat good condition. It needs routine and preventive maintenance to maintain a relatively good performance level. The pavement is starting to deteriorate and is approaching a critical PCI. Suggested types of improvement include corrective maintenance and deferred actions. Recommended PCI range is 56-70.

- **Level of Service D:** A pavement is in fair condition, continuing to deteriorate and starts suffering a reduction in performance levels (Plate 6). Beyond this level, the rate of pavement deterioration and the cost of repair increase significantly. This level represents a critical pavement condition. Suggested types of improvement include corrective maintenance and minor rehabilitation consisting of non-structural enhancements. Recommended PCI range is 41-55.
- **Level of Service E:** A pavement is in poor condition. It has deteriorated so much such that preventive and corrective maintenances are no longer cost-effective. The pavement suffers a major reduction in performance level (Plate 7). It may be kept in this level until budgets permit major rehabilitation. Recommended PCI range is 26-40.

	
Plate 5: Pavement in Excellent Condition The pavement is smooth and generally free of distress.	**Plate 6: Pavement in Fair Condition** Cracking is extensive and the pavement surface is weathered. The pavement shows signs of structural damage.
	**Plate 7: Pavement in Very Poor Condition** The pavement surface is cracked and disintegrated. Structural damage is widespread. The ride has deteriorated to the point where traffic operations are affected.

- **Level of Service F:** A pavement is in failed condition. Major reconstruction or replacement is needed. Recommended PCI range is 0-25.

Figure 3.16 presents suggested maintenance and rehabilitation feasible actions for flexible pavements. It should be noted, however, that exact actions are site specific.

The broad M&R strategies needed for the roadway network will be determined based upon only the current PCI of pavements, therefore, the road maintenance agency will be able to roughly prepare or plan their budget at network level.

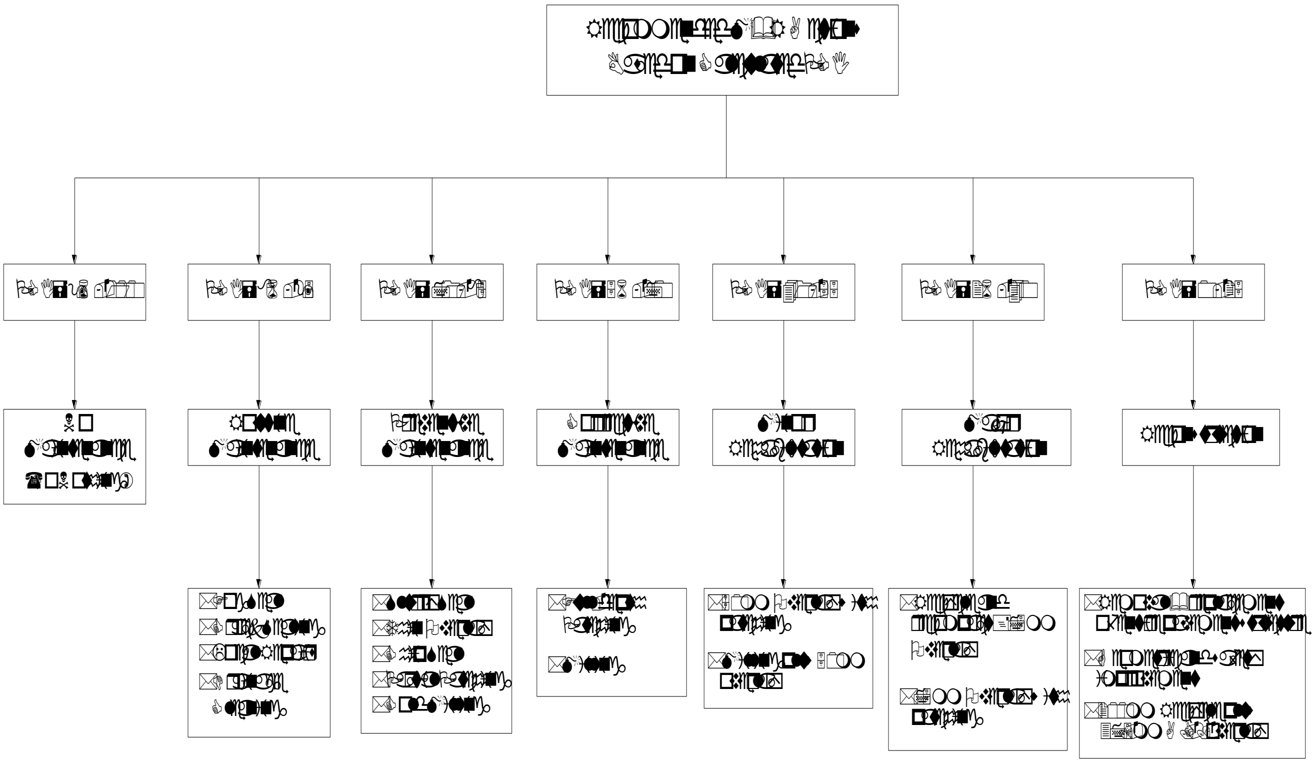


Figure 3.14: Suggested M&R Feasible Actions for Flexible Pavements in Nigeria

3.10 GENERATING THEMATIC REPORTS

In addition to presentation of survey and analysis reports in tabular formats, the developed PIMS also has the capability of displaying reports for the entire roads network in thematic map formats. Towards this end, all the available federal road sections within the network were digitized using ArcMap-ArcView program (Figure 3.15). Each digitized road section was assigned a unique name (same as the federal route number). Links were then established between the digitized road sections and road sections listed in the PIMS database. As such, it is possible to attach survey and analysis results to specific road sections which are then appropriately displayed in the road network map.

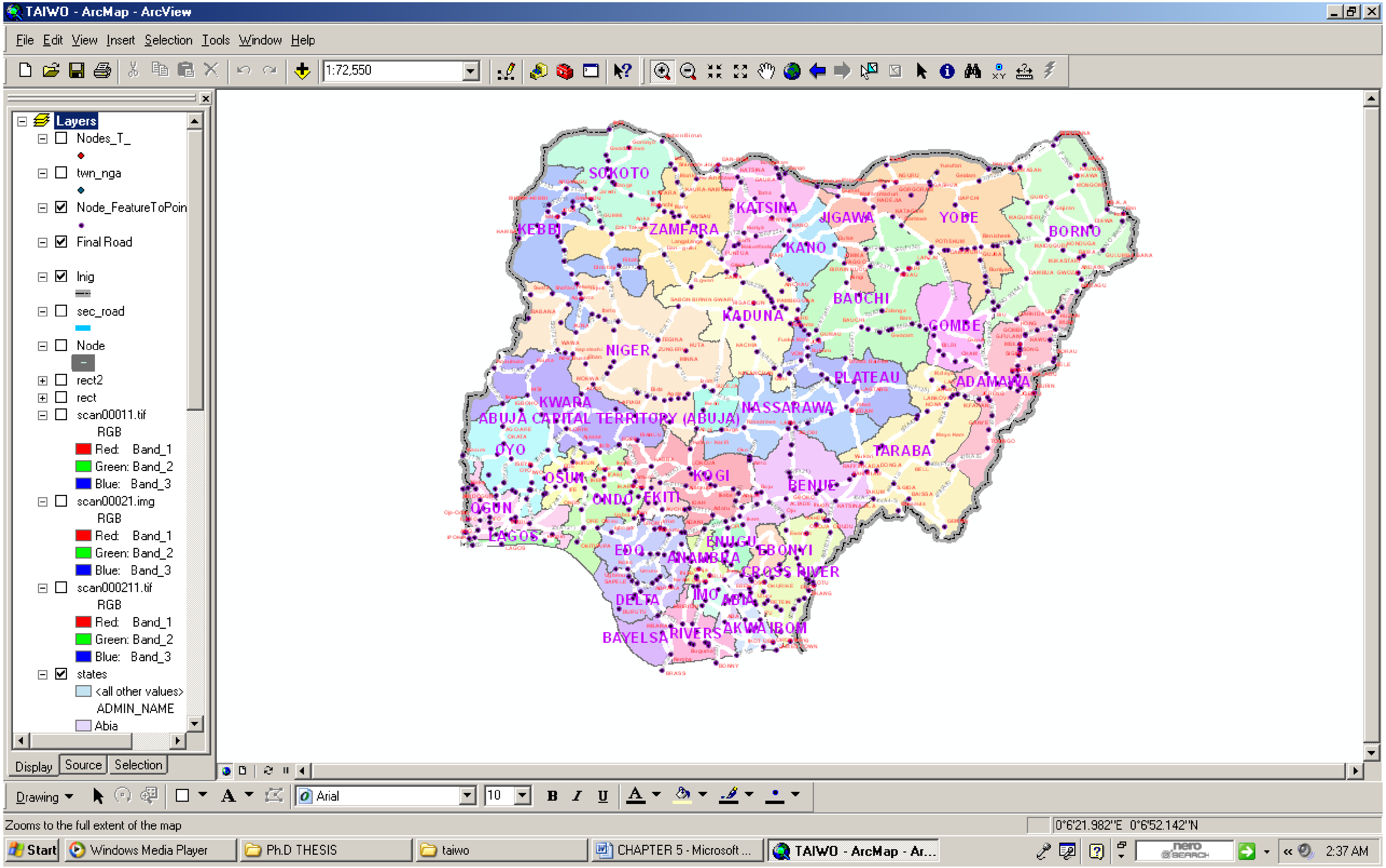


Figure 3.15: Digitized Federal Road Network of Nigeria using ArcMap-ArcView Program

3.11 REFERENCING SYSTEM

The primary purpose of the referencing system is to accurately define and identify the pavement sections within the digitized federal road network of Nigeria. This was accomplished by establishing a standard section and node system that could be utilized (in future) to store all linear data related to road centrelines. The linear data that could be stored include inventory of roadway features and roadway characteristics, e.g., road width, number of lanes, pavement thickness, etc. The linear data stored, in this study, are basically the route number and description of all rural highways within the network. An established link with the MATLAB/Visual Basic applications will enable results of analyses to be extracted and displayed for each pavement in the PIMS interface.

Nodes and sections of pavements within the federal roads network map were identified according to FMW categorization as detailed in the Inventory of Federal Roads [FMWH, 1999]. Nodes were defined as points in the road network and identified at road intersections or administrative/state boundaries. The adopted procedure utilized to capture the road network centreline, the challenges encountered and the maps used are all documented in Appendices F - I.

State boundaries of roads were clearly identified and demarcated. A section represents the length of a road measured along the centreline between start and end nodes. The node that represents the end of a section defines the section’s limit and location. Figure 3.16 shows the digitized locational referencing of a section of the federal rural road network indicating nodes and sections.

3.12 THEMATIC DISPLAY CAPABILITIES OF THE DEVELOPED PIMS

The developed PIMS is capable of reporting and displaying pavement and traffic information for the entire network of highways. The system is able to display information spatially as well as temporally. Spatial information on traffic (ADT), type of pavement rehabilitation (M&R Action), and pavement condition (PCI Category), can be presented for the highway system in the form of different themes. Temporal information can be displayed based on user-selection of a particular year.

User interfaces are provided which facilitate easy selection of the different types of display of results (from the analyses previously carried out in MATLAB/Visual Basic environment).

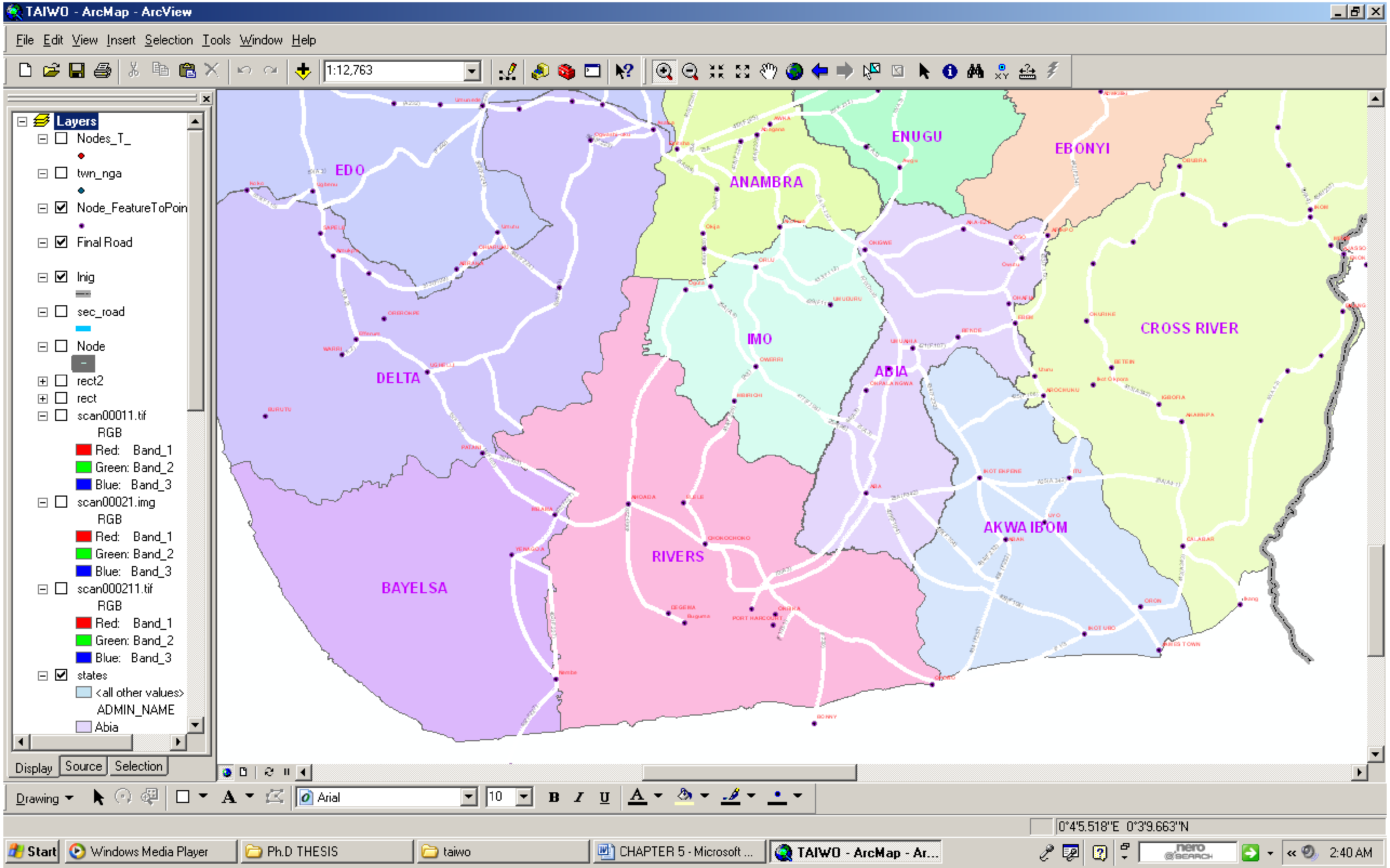
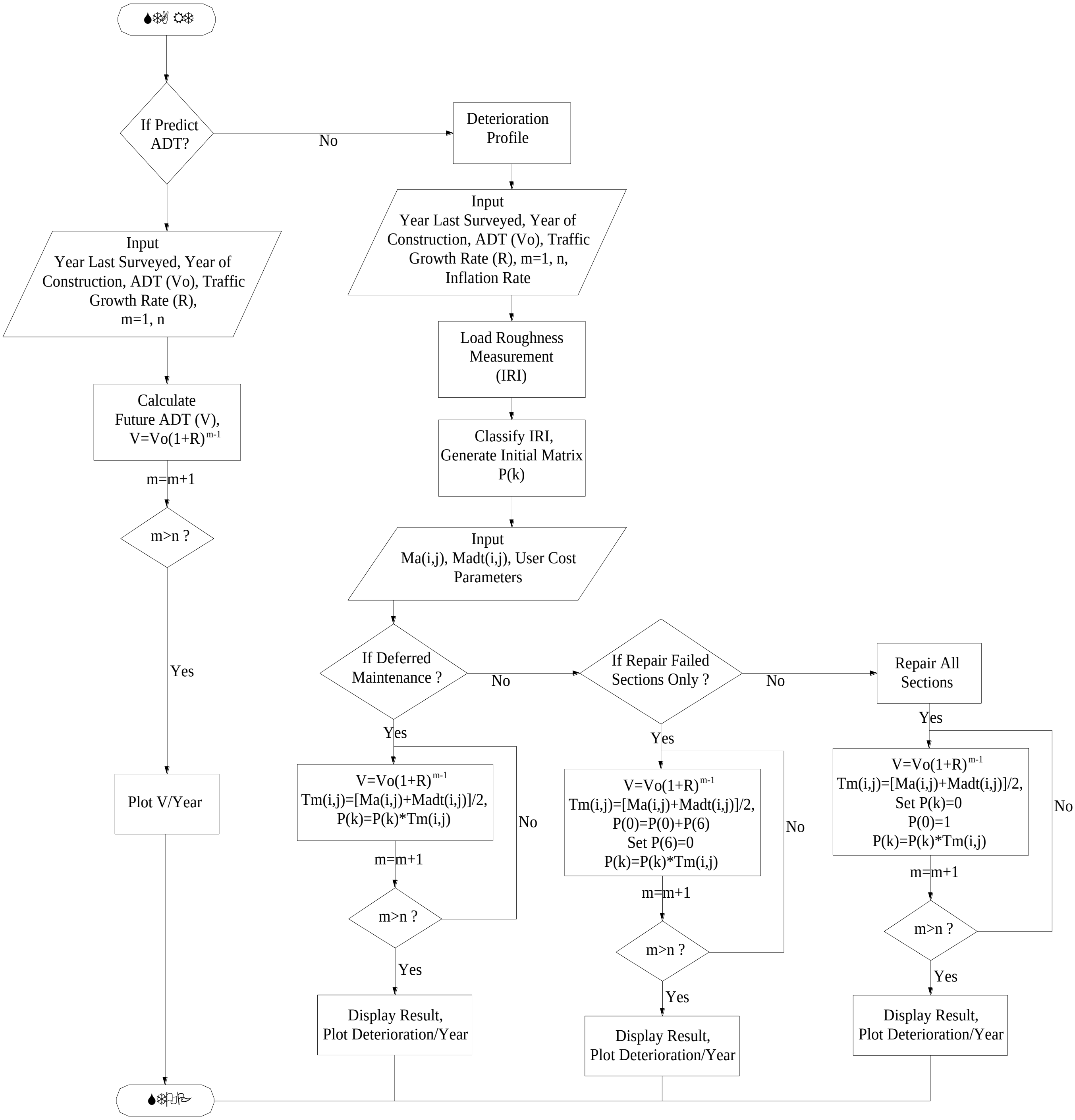


Figure 3.16: Locational Referencing of a Section of the Federal Rural Road Network Showing Nodes and Sections

3.13 PROCEDURE FOR PAVEMENT PERFORMANCE AND USER COSTS PREDICTION MODELLING

The flowchart in Figure 3.17 gives an overview of the procedure utilized for the pavement performance and user costs prediction modelling.



Ma=Transition matrix for age range; Madt=Transition matrix for ADT range; ADT = Annual Daily Traffic

Figure 3.17: Flowchart of the Procedure for Pavement Performance and User Costs Prediction Modelling

3.14a MARKOV APPROACH TO PREDICTING PAVEMENT PERFORMANCE

A system which can exist in one of a set of possible states and which varies unpredictably over time is a candidate for description in Markovian Terms [Benjamin and Cornell, 1970]. Road pavement is likened to such a system with a finite (N+1) number of states, labelled 1, 2, 3, … N and it is assumed that the system is always in one of these states while transition is in discrete steps. At discrete points in time, the system makes a transition from one state to another (or remains in the same state). If the probability of transition to other states depends only on the state currently occupied and not on the history of the system, the system is called a "finite-state Markovian Chain".

Markov chains are conveniently represented in matrix notation. The state of the system is specified by a row vector of length (N+1), the elements of which constitute a probability distribution over a set of possible states. The transition probabilities are arranged in an [1+N] x [N+1] matrix, the *i, j* element representing the probability that the system will undergo a transition from state *i* to *j* in a single step. If the system is initially described by a specific probability distribution over the N states (the row vector), and if the transition matrix is also specified, the state of the system after one transition may be obtained directly by matrix multiplication.

3.14b PROPOSED MARKOV MODELLING

The first step in the modelling is the specification of the initial state of the pavement. In this work, following the previous research works in this area by Atume [1992] and Ezemenari [1999], the different states of a pavement are described by roughness measurement. The next step is the development of the transition probability matrix. The choice of transition probabilities may be made, in the first pass, by engineering measurement informed by maintenance experience. Many researchers have used questionnaires to obtain judgements from a panel of experts. Another alternative is to set a functional form for the decay of the state of pavement, and then fix the transition probabilities by varying the decay parameters.

Once the initial state and transition matrices are specified, the new state of the pavement is calculated by matrix multiplication. Each multiplication of the state vector by the transition matrix represents one transition in the state of the pavement. The multiplication process continues until the required number of transitions has been completed or the system reaches a steady state.

It should be noted that the mathematics of a Markov Chain says nothing about how much time elapses between transitions. In order to compare predictions with the real world, it is therefore necessary to set the time scale. This corresponds to specifying the average length of time in some convenient units that is to be associated with the interval between transitions. For this work, one year has been adopted as the interval between transitions.

3.15 DEVELOPMENT OF MODELS FOR CASE STUDY

3.15.1 BASIS FOR CATEGORIZATION

For effective implementation of maintenance strategies, it is desirable that the pavement be divided into different sections according to their specific state of disrepair. This approach has the main advantage of efficient budget allocation to repair sections in urgent maintenance needs first. There are many methods of rating a road pavement using different distress manifestations. However, for this work, roughness has been chosen as the rating method for the purpose of development of models.

3.15.2 DEFINITION OF DIFFERENT STATES OF A ROAD PAVEMENT USING ROAD ROUGHNESS MEASURE

In line with the recommendation of TRRL Road Note 5 [Kerali, 2003], seven different states of any pavement have been considered, to correspond to the seven M&R strategies adopted, and shown in Table 3.4. For the application of the developed PIMS, the roughness data collected for Kano – Maiduguri Road in year 2005 by Pavement Evaluation Unit of the Federal Ministry of Works, Katabu-Kaduna, was used. This case study road is 125.5km long and the roughness data is presented as Appendix J.

TABLE 3.4: STATES OF PAVEMENT BASED ON ROUGHNESS MEASUREMENT

STATE OF THE ROAD	CONDITION	LIMITING ROUGHNESS	MID VALUES OF ROUGHNESS VALUES	
		IRI (m/Km)	IRI	BI (m/Km)
1	Excellent	0.0 - 1.9	0.95	600
2	Very Good	2.0 - 3.9	2.95	2140
3	Good	4.0 - 5.9	4.95	3830
4	Fair	6.0 - 7.9	6.95	5610
5	Poor	8.0 - 10.0	8.95	7460
6	Very poor	10.0 – 12.0	10.95	9360
7	Failed	> 12.0	> 11.95	10320

Source: Kerali, 2003 (Adapated)

The steps to capture the proportions of a road section that fall within each condition rating, based on the supplied roughness data, are indicated in the flowchart of Figure 3.18. These steps are programmed into the PIMS such that, for any pavement with known roughness data for any year, the initial probability vector, P_o, can be automatically generated.

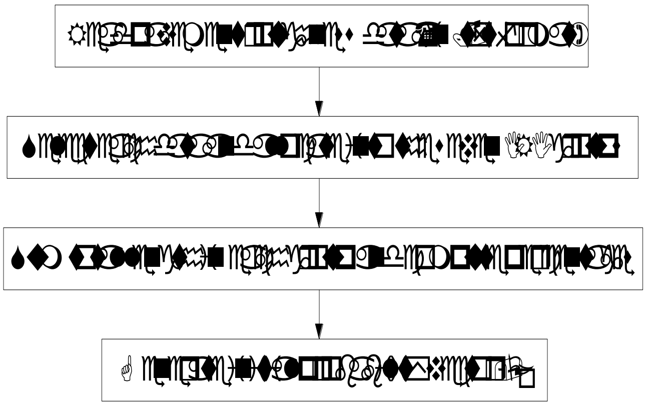


Figure 3.18: System's Flowchart to Generate P_o from Known Roughness Data

<u>International Roughness Index (IRI) and Bump Integrator (BI)</u>

The international roughness index (IRI) is used to define a characteristic of the longitudinal profile of a travelled wheel track and constitutes a standardized roughness measurement. The commonly recommended units are meters per kilometre (m/km) or millimetres per meter (mm/m). The IRI is based on the average rectified slope (ARS), which is a filtered ratio of a standard vehicle's accumulated suspension motion (in mm, inches, etc.) divided by the distance travelled by the vehicle during the measurement (km, mi, etc.).

Bump Integrator (BI) gives quantitative integrated evaluation of surface irregularities. The wheel of Bump Integrator runs on the pavement surface and the vertical reciprocating motion of the axle is converted into unidirectional rotary motion by an integration unit. A relationship exists between the standard roughness index IRI (m/km) and the roughness measure based on the BI, i.e.

$$BI = 630(IRI)^{1.12} \qquad (3.7)$$

where BI is expressed in mm/km and IRI is expressed in m/km.

Using the roughness data, the 125.5km case study road was automatically proportioned by the PIMS into different condition states. The result is given in Table 3.5.

From the results of these proportions, an initial probability vector P_o, is obtained as:

$$P_o = [\ 0.772908 \quad 0.227092 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0]$$

TABLE 3.5: PROPORTIONS OF THE CASE STUDY ROAD UNDER DIFFERENT STATES

STATE	LENGTH OF THE ROAD FALLING INTO STATE (km)	PROPORTION OF THE TOTAL LENGTH
1	97	0.772908
2	28.5	0.227092
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
TOTAL	**125.5**	**1**

3.15.3 DEVELOPMENT OF TRANSITION PROBABILITY MATRICES

Transition probability matrix (TPM) has conventionally been developed using questionnaires that required the subjective judgement of experienced highway engineers in the Ministry of Transportation. Past work carried out [Atume, 1992 and Ezemenari, 1999] developed and used a single TPM based on the condition of the case study road. The limitations of this method include non-cognizance of important parameters such as the age (last construction or major rehabilitation date), and traffic volume of a road. It is obvious that the rate of deterioration of any road will definitely be affected by these two important parameters.

In order to improve on the reliability of deterioration modelling, this study attempts to develop several TPMs that reflect these two major road parameters affecting pavement deterioration. The ranges of values for age and traffic volume considered in this work are listed in Figure 3.19. It is believed that specification of age spectrum for a road would have taken care of environmental effects on the road while range of traffic volume would take care of road class. In addition, traffic growth rate is assumed constant for the analysis period.

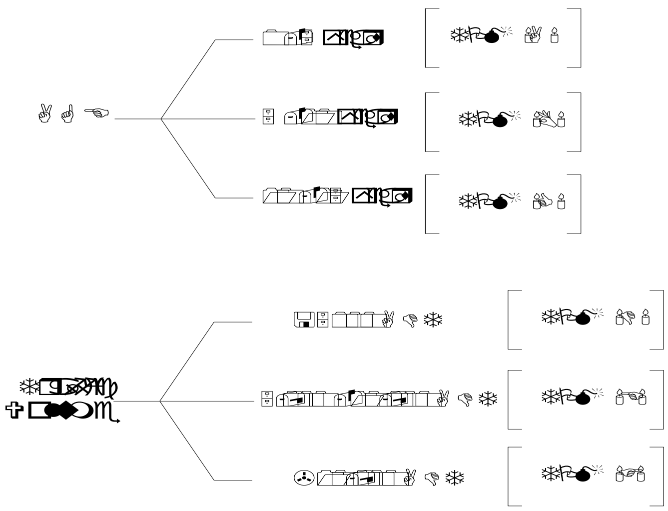


Figure 3.19: Ranges for Parameters Considered in TPM Development

Thus, six TPM ‘A’ to ‘F’ were expanded out from the previous TPM developed by Atume (1992) and Ezemenari (1999) as shown below. The format of the questionnaire used for the development of the original TPM and the resulting TPM are shown in Appendix K.

Transition Probability Matrix (Age 1-5 years)

$$TPM\ A_{ij} = \begin{bmatrix} 0.90 & 0.05 & 0.02 & 0.01 & 0.008 & 0.007 & 0.005 \\ 0 & 0.85 & 0.06 & 0.04 & 0.02 & 0.02 & 0.01 \\ 0 & 0 & 0.85 & 0.06 & 0.04 & 0.03 & 0.02 \\ 0 & 0 & 0 & 0.80 & 0.10 & 0.07 & 0.03 \\ 0 & 0 & 0 & 0 & 0.80 & 0.15 & 0.05 \\ 0 & 0 & 0 & 0 & 0 & 0.75 & 0.25 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Transition Probability Matrix (Age 6-10 years)

$$TPM\ B_{ij} = \begin{bmatrix} 0.80 & 0.06 & 0.05 & 0.04 & 0.03 & 0.02 & 0.01 \\ 0 & 0.75 & 0.09 & 0.07 & 0.05 & 0.03 & 0.01 \\ 0 & 0 & 0.75 & 0.10 & 0.08 & 0.04 & 0.03 \\ 0 & 0 & 0 & 0.70 & 0.15 & 0.09 & 0.06 \\ 0 & 0 & 0 & 0 & 0.70 & 0.20 & 0.10 \\ 0 & 0 & 0 & 0 & 0 & 0.65 & 0.35 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Transition Probability Matrix (Age 11-15 years)

$$TPM\ C_{ij} = \begin{bmatrix} 0.70 & 0.10 & 0.07 & 0.06 & 0.04 & 0.02 & 0.01 \\ 0 & 0.65 & 0.12 & 0.09 & 0.07 & 0.05 & 0.02 \\ 0 & 0 & 0.65 & 0.20 & 0.08 & 0.04 & 0.03 \\ 0 & 0 & 0 & 0.60 & 0.25 & 0.15 & 0.10 \\ 0 & 0 & 0 & 0 & 0.60 & 0.30 & 0.10 \\ 0 & 0 & 0 & 0 & 0 & 0.55 & 0.45 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Transition Probability Matrix (ADT ≤ 5,000)

$$TPM\ D_{ij} = \begin{bmatrix} 0.95 & 0.01 & 0.008 & 0.006 & 0.006 & 0.002 & 0.001 \\ 0 & 0.90 & 0.03 & 0.01 & 0.008 & 0.007 & 0.005 \\ 0 & 0 & 0.90 & 0.04 & 0.03 & 0.02 & 0.01 \\ 0 & 0 & 0 & 0.85 & 0.10 & 0.03 & 0.02 \\ 0 & 0 & 0 & 0 & 0.85 & 0.10 & 0.05 \\ 0 & 0 & 0 & 0 & 0 & 0.80 & 0.20 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Transition Probability Matrix (ADT : 5,001 – 10,000)

$$TPM\ E_{ij} = \begin{bmatrix} 0.85 & 0.07 & 0.04 & 0.02 & 0.008 & 0.007 & 0.005 \\ 0 & 0.80 & 0.08 & 0.05 & 0.04 & 0.02 & 0.01 \\ 0 & 0 & 0.80 & 0.08 & 0.06 & 0.04 & 0.02 \\ 0 & 0 & 0 & 0.75 & 0.15 & 0.07 & 0.03 \\ 0 & 0 & 0 & 0 & 0.75 & 0.15 & 0.10 \\ 0 & 0 & 0 & 0 & 0 & 0.70 & 0.30 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Transition Probability Matrix (ADT : ≥10,000)

$$TPM\ F_{ij} = \begin{bmatrix} 0.80 & 0.07 & 0.05 & 0.03 & 0.02 & 0.02 & 0.01 \\ 0 & 0.75 & 0.10 & 0.06 & 0.04 & 0.03 & 0.02 \\ 0 & 0 & 0.75 & 0.15 & 0.10 & 0.06 & 0.04 \\ 0 & 0 & 0 & 0.70 & 0.15 & 0.10 & 0.05 \\ 0 & 0 & 0 & 0 & 0.70 & 0.20 & 0.10 \\ 0 & 0 & 0 & 0 & 0 & 0.65 & 0.35 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Any pavement section in the network would be categorized into a specific combination of age and traffic volume spectra. The PIMS will automatically select and combine the TPMs corresponding to the specified age and ADT ranges of any selected road and utilize the combined TPM to perform the deterioration analysis.

3.16 USER COSTS MODELLING

Studies [Robinson, 1986] carried out by TRRL in some developing countries indicate that on a badly maintained two lane bituminous road with a design life of ten years and carrying 750 vehicles per day, the incremental vehicle operating costs would amount to ten times the costs necessary to maintain it at or near the constructed level of service tallying with a figure of between one million U.S. dollars to five million U.S. dollars per year per one hundred kilometre length of the road.

The World Bank [Morosiur, 2004] has also estimated that while more than ten thousand U.S. million dollars are spent each year on highway construction, maintenance and administration by governments in developing countries of Africa, Asia and Latin America, the costs borne directly by the road users for vehicle operation might well be in the order of ten times this amount.

Basically, road user costs consist of time costs and vehicle operating costs. It is intended to ignore the time component of user cost in this work, primarily because time costs in developing economies usually have low values. The user cost model therefore, considers the vehicle operating cost as the major component.

Vehicle operating costs depend on the number and type of vehicles using the road, the geometric design standards of the road, particularly of the curvature, gradient and road width, the condition of the surface of the road, primarily its unevenness or "roughness" and driver's behaviour. Roughness at any time will depend on whether the road is earth, gravel or paved, on the climate in the vicinity of the road, on the traffic it has carried and on the type and level of maintenance that has been carried out in the past. The value of roughness will change with time depending on traffic loading, the performance of the materials with which the road is built and type and amount of maintenance that is carried out. The change in roughness can have an appreciable effect on the vehicle operating costs throughout the life of a road. The components of vehicle operating cost normally considered are [Morosiur, 2004]:

(a) Fuel consumption
(b) Lubricating oil consumption
(c) Spare parts consumption
(d) Vehicle maintenance labour hours
(e) Tyre consumption (Wear and Tear)
(f) Vehicle depreciation
(g) Crew cost
(h) Overheads

3.16.1 VEHICLE SPEEDS

These are major determinant of vehicle operation costs. In calculating speed, the following relationships exist for each class of vehicle [Kerali, 2003]:

$$V_C = S_c + (0.483 - 0.00833\,S_c)RS - (0.025 - 0.0005\,S_c)F + (0.115 - 0.0022\,S_c)C - 0.000087\,R \qquad (3.8)$$

$$V_T = 49.0 + (1.429 - 0.0286S_T)RS - (0.867 - 0.01318S_T)F + (0.177 - 0.00346S_T)C - (1.90 - 0.04346S_T)PW - 0.00106R \qquad (3.9)$$

where:

V_C = speed of cars in km/h
V_T = speed of trucks in km/h
S_C = observed free speed of cars in km/h
S_T = observed free speed of trucks in km/h
RS = rise in m/km
F = fall in m/km
C = curvature in degrees/km
R = roughness in mm/km
PW = power to weight ratio in brake horsepower/tonne (BHP/tonne)

Table 3.6 indicates the maximum safe range of application for each variable in the equations. If these values are exceeded, the estimates are not considered to be reliable (Hide, 1982).

TABLE 3.6: MAXIMUM SAFE RANGE OF APPLICATION FOR EACH VARIABLE

Variable	Units	Maximum safe range
Rise, RS	m/km	0 - 85
Fall, F	m/km	0 - 85
Horizontal curvature, C	degrees/km	0 - 200

Courtesy: TRRL Supplementary Report 223 UC [1982]

3.16.2 FUEL CONSUMPTION

Fuel consumption should be calculated for each half percent increment in road gradient and for the two directions of traffic in order to provide the mean value of each class of vehicle. The TRRL report 1057 gives the following relationships to use:

$$FL_C = \left(24 + \frac{969}{V} + 0.0076V^2 + 1.33RS - 0.63F + 0.0029F^2 \right) 1.08 \quad (3.10)$$

$$FL_B = \left(29 + \frac{2219}{V} + 0.0203V^2 + 0.848(GVW * RS) - 2.6F + 0.0132F^2 \right) 1.13 \quad (3.11)$$

where:

FL_C = Fuel consumption of cars in millilitres per km
FL_B = Fuel consumption of buses and trucks in millilitres per km
V = Speed in km/hr
RS = Rise in m/km
F = Fall in m/km
GVW = Gross vehicle weight in tonnes

The maximum safe range of each variable is shown in Table 3.7. Applications beyond these ranges could lead to unacceptable errors in the estimates.

TABLE 3.7: RANGE OF VARIABLES FOR ESTIMATING VEHICLE FUEL CONSUMPTION ON PAVED ROADS

Variable	Units	Maximum safe range
Rise, RS	m/km	0 - 85
Fall, F	m/km	0 - 85
Speed V_c (for cars)	km/h	20 - 140
Speed V_T (for trucks)	km/h	5 - 100
Power/weight ratio, PW	BHP/tonne	40:1 – 5:1
Gross Vehicle Weight, GVW	Tonnes	8.5 - 40

Courtesy: TRRL Supplementary Report 223 UC [1982]

3.16.3 TYRE CONSUMPTION (WEAR AND TEAR)

The basic relationships used are [Kerali, 2003]:

$$TC_C = \left(\frac{0.0927 + 0.06275\, e^Z}{1 + e^Z}\right) 10^{-3}; \quad Z = -3.753 + 0.000695R \tag{3.12}$$

$$TC_B = \left(\frac{0.1054 + 0.19215\, e^Z}{1 + e^Z}\right) * GVW * 10^{-4}; \quad Z = -4.302 + 0.00737R \tag{3.13}$$

where

- TC_C = Tyre consumed per kilometre for cars
- TC_B = Tyre consumed per kilometre for buses and trucks
- R = Roughness in mm/km
- GVW = Gross vehicle weight in tonnes

N.B. Tyre consumption in cars is dependent only on road roughness while gross vehicle weight is an additional factor for trucks.

3.16.4 SPARE PARTS CONSUMPTION

The basic relationships used are [Kerali, 2003]:

$$PC_C = \left(\frac{1.57 + 18.08\, e^Z}{1 + e^Z}\right) * K * VP * 10^{-11}; \quad Z = -4.673 + 0.000812 * R \tag{3.14}$$

$$PC_T = \left(\frac{1.22 + 6.0\, e^Z}{1 + e^Z}\right) * K * VP * 10^{-11}; \quad Z = -4.879 + 0.00984 * R \tag{3.15}$$

where

- PC_C = Spare parts costs per kilometre for cars
- PC_T = Spare parts costs per kilometre for trucks
- R = Roughness in mm/km
- VP = Price of an equivalent new vehicle
- K = Total kilometres run to date (this is determined from the product of the average annual kilometres run and the average age of the vehicle, which is, in turn, found from the age spectrum)

3.16.5 MAINTENANCE LABOUR HOURS

The following basic relationships are used [Kerali, 2003]:

$$LH_C = \left(\frac{695 + 383\, e^Z}{1 + e^Z}\right) * \frac{PC}{VP}; \quad Z = -6.373 + 0.00159 * R \tag{3.16}$$

$$LH_T = \left(\frac{2819 + 250\, e^Z}{1 + e^Z} \right) * \frac{PC}{VP}; \quad Z = -6.373 + 0.00159*R \tag{3.17}$$

where

LH_C, LH_T = Labour hours of maintenance for cars and trucks respectively
PC = Spare parts costs per kilometre determined in Section 4.4.4
VP = Price of an equivalent new vehicle
R = Roughness in mm/km

3.16.6 CREW HOURS COST

This is the cost of maintaining the crew of the vehicle. This involves light passenger vehicles, buses and trucks. There are normally no crew costs for private cars. It is determined by the number of crew that a vehicle carries, their wages and the overheads of employing them. The following relationship is used for all vehicle types (except private cars) regardless of road types [Cundill and Withnall, 1995]:

$$CC = \left(\frac{NC * CW(100 - PP}{100} \right) * TI \tag{3.18}$$

where

CC = crew cost per km
NC = number of crew
CW = crew wages (per person per hour)
PP = percentage of private cars
TI = travel time (hours per km) = $1/V_T$
V_T = speed of buses and trucks in km/hr

3.16.7 DEPRECIATION COST

Depreciation means the gradual decrease in the value of an asset due to wear and tear with passage of time. Most assets (including vehicles) become less valuable each passing year, eventually requiring replacement. The following relationship is used for all vehicle types regardless of road types [Cundill and Withnall, 1995]:

$$DC = \frac{AD * PN * VP(100 - PP)}{10^6} * \frac{TI}{WH} \tag{3.19}$$

where

DC = Depreciation cost per km
AD = annual depreciation as a percentage of the current vehicle value
PN = current vehicle value as a percentage of the price of a new vehicle
VP = price of an equivalent new vehicle
WH = working hours per year
PP = percentage of private vehicles
TI = travel time (hours per km)

3.15.8 LUBRICATING OIL CONSUMPTION

Average figures for total oil consumption on paved roads are given in Table 3.8.

TABLE 3.8: AVERAGE FIGURES FOR TOTAL OIL CONSUMPTION

CLASS OF VEHICLE	OIL CONSUMPTION
Passenger cars	1.2 litres/1000km
Light goods vehicle	1.8 litres/1000km
Medium & heavy goods vehicles	4.0 litres/1000km

Source: Hide, 1982

3.16.9 OVERHEADS

TRRL has found through studies that overhead costs is a fixed percentage of total running costs with twenty percent for trucks and buses and ten percent for cars [Atume, 1992].

3.17 EVALUATION OF USER COST MODEL

The user cost model is developed by generating values for each component of the vehicle operating cost using the given equations. The variable user-changeable components from the equations have been collated within the developed PIMS in the format of a form (Figure 3.20). Default values, based on year 2008, have been provided, though all the default values are user-changeable.

3.17.1 VEHICLE SPEEDS

By adopting equations 3.8, and 3.9, and using observed free-speed (km/h) of 100 and 80 for cars and trucks, respectively, the speeds for cars and trucks for the case study road are given in Table 3.9.

TABLE 3.9: VEHICLE SPEEDS

STATE OF THE ROAD	SPEED OF CARS (km/h)	SPEED OF TRUCKS (km/h)
1	75.02	35.56
2	73.78	33.92
3	72.43	32.13
4	71.01	30.24
5	69.53	28.28
6	68.01	26.27
7	67.24	25.25

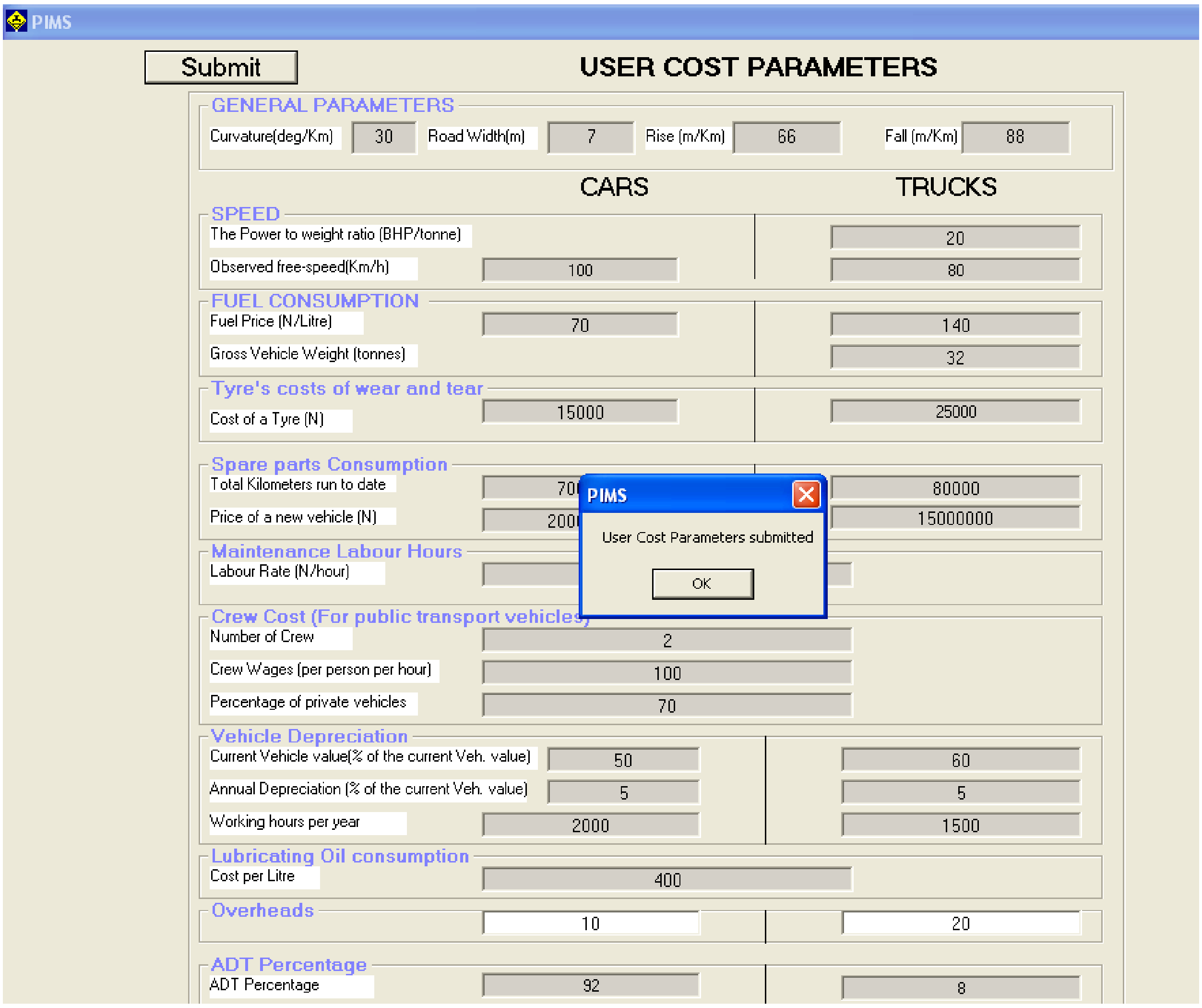


Figure 3.20: User Costs Parameters Form (with Current Default Values)

3.17.2 FUEL CONSUMPTION

By using equations 3.10, and 3.11, and taking fuel price (N/Litre) as 70 for cars and 140 for trucks and gross vehicle weight (tonnes) for trucks as 32, the fuel consumption for the case study road was computed as in Table 3.10.

TABLE 3.10: FUEL CONSUMPTION FOR CARS AND TRUCKS

STATE OF THE ROAD	CONSUMPTION FOR CARS (N PER KILOMETRE)	CONSUMPTION FOR TRUCKS (N PER KILOMETRE)
1	10.05	192.33
2	9.96	192.45
3	9.86	192.66
4	9.77	192.98
5	9.67	193.45
6	9.57	194.09
7	9.52	194.49

3.17.3 TYRE CONSUMPTION (WEAR AND TEAR)

Using equations 3.12 and 3.13, and taking the costs of a car tyre as N15,000 and that of truck tyre N25,000, tyre consumption costs was generated for the case study road as in Table 3.11.

TABLE 3.11: TYRE CONSUMPTION COSTS FOR CARS AND TRUCKS

STATE OF THE ROAD	TYRE CONSUMPTION FOR CARS (N PER KILOMETRE)	TYRE CONSUMPTION FOR TRUCKS (N PER KILOMETRE)
1	1.67	48.24
2	2.14	49.83
3	3.41	54.67
4	5.69	65.31
5	7.87	77.39
6	8.93	83.74
7	9.16	85.06

3.17.4 SPARE PARTS CONSUMPTION

Using equation 3.14 and taking K (total kilometre run to date) as 70,000 km and VP (price of an equivalent new car) as N2,000,000 (two million naira), the spare parts consumption can be computed. Similarly, from equation 3.15 and assuming the cost of a truck as N15,000,000 (fifteen million naira) and K is 80,000 km, the spare parts consumption can also be computed. Table 3.12 shows the results.

TABLE 3.12: SPARE PARTS CONSUMPTION FOR CARS AND TRUCKS

STATE OF THE ROAD	SPARE PARTS CONSUMPTION FOR CARS (N PER KILOMETRE)	SPARE PARTS CONSUMPTION FOR TRUCKS (N PER KILOMETRE)
1	23.17	67.45
2	30.63	78.80
3	56.48	126.24
4	119.08	228.43
5	188.36	295.28
6	219.82	311.74
7	225.48	313.72

3.17.5 EVALUATION OF MAINTENANCE LABOUR HOURS

By adopting equations 3.16, and 3.17, and using labour rate (N/hour) of 1200, the maintenance costs for cars and trucks were generated for the case study road as in Table 3.13.

TABLE 3.13: MAINTENANCE LABOUR COSTS FOR CARS AND TRUCKS

STATE OF THE ROAD	CARS (N PER KILOMETRE)	TRUCKS (N PER KILOMETRE)
1	0.57	3.26
2	0.74	3.79
3	1.19	5.81
4	1.71	9.91
5	2.56	12.70
6	2.97	13.40
7	3.04	13.48

3.17.6 CREW HOUR COSTS (APPLICABLE ONLY TO TRUCKS)

From equation 3.18 and taking the number of crew as 2, crew wages (per person per hour) as 100 and percentage of private vehicles as 70; crew hour costs for trucks were generated for the case study road as depicted in Table 3.14.

TABLE 3.14: CREW HOUR COSTS

STATE OF THE ROAD	CREW HOUR COSTS (TRUCKS) (N PER KILOMETRE)
1	6.33
2	6.63
3	7.00
4	7.44
5	7.95
6	8.56
7	8.91

3.17.7 DEPRECIATION COSTS

By adopting equation 3.19 and taking current vehicle values (% of the current vehicle value) as 50 and 60; annual depreciations (% of the current vehicle value) as 5 and 5; and working hours per year as 2000 and 1500 for cars and trucks respectively, depreciation costs for the case study road were generated as in Table 3.15.

TABLE 3.15: DEPRECIATION COSTS

STATE OF THE ROAD	CARS (N PER KILOMETRE)	TRUCKS (N PER KILOMETRE)
1	0.60	1.85
2	0.61	1.93
3	0.62	2.04
4	0.63	2.17
5	0.65	2.32
6	0.66	2.50
7	0.67	2.60

3.17.8 LUBRICATING OIL CONSUMPTION

By adopting oil consumption of 1.2 litres/1000km for cars, 4.0 litres/1000km for trucks, and cost per litre of N400, the lubricating oil consumption costs for the case study road were generated as in Table 3.16.

TABLE 3.16: LUBRICATING OIL CONSUMPTION COSTS

STATE OF THE ROAD	CARS (N PER KILOMETRE)	TRUCKS (N PER KILOMETRE)
1	0.48	1.60
2	0.48	1.60
3	0.48	1.60
4	0.48	1.60
5	0.48	1.60
6	0.48	1.60
7	0.48	1.60

3.17.9 OVERHEAD COSTS

The overhead cost is taken as a fixed percentage of total running costs with twenty (20) percent for trucks and ten (10) percent for cars. The overhead costs generated for the case study road are presented in Table 3.17.

TABLE 3.17: OVERHEAD COSTS

STATE OF THE ROAD	CARS (N PER KILOMETRE)	TRUCKS (N PER KILOMETRE)
1	3.65	16.05
2	4.46	16.75
3	7.20	19.50
4	13.74	25.39
5	20.96	29.53
6	24.24	30.78
7	24.84	30.99

3.17.10 CONTRIBUTIONS OF DIFFERENT COMPONENTS OF VEHICLE OPERATING COSTS

The contribution of the different components of vehicle operating costs for cars and trucks, for the case study road, are shown in Tables 3.18 and 3.19, respectively.

TABLE 3.18: CONTRIBUTIONS OF DIFFERENT COMPONENTS OF VEHICLE OPERATING COSTS FOR CARS

STATE	A	B	C	D	E	F	G	H	TOTAL
1	10.05	1.67	23.17	0.57	-	0.60	0.48	3.65	40.19
2	9.96	2.14	30.63	0.74	-	0.61	0.48	4.46	49.02
3	9.86	3.41	56.48	1.19	-	0.62	0.48	7.20	79.24
4	9.77	5.69	119.08	1.71	-	0.63	0.48	13.74	151.10
5	9.67	7.87	188.36	2.56	-	0.65	0.48	20.96	230.55
6	9.57	8.93	219.82	2.97	-	0.66	0.48	24.24	266.67
7	9.52	9.16	225.47	3.05	-	0.67	0.48	24.84	273.19

TABLE 3.19: CONTRIBUTIONS OF DIFFERENT COMPONENTS OF VEHICLE OPERATING COSTS FOR TRUCKS

STATE	A	B	C	D	E	F	G	H	TOTAL
1	192.33	48.24	67.45	3.26	6.33	1.85	1.60	16.05	337.11
2	192.45	49.83	78.80	3.79	6.63	1.93	1.60	16.75	351.78
3	192.66	54.67	126.24	5.81	7.00	2.04	1.60	19.50	409.52
4	192.98	65.31	228.43	9.91	7.44	2.17	1.60	25.39	533.23
5	193.45	77.39	295.28	12.70	7.95	2.32	1.60	29.53	620.22
6	194.09	83.74	311.74	13.40	8.56	2.50	1.60	30.78	646.41
7	194.49	85.06	313.72	13.48	8.91	2.60	1.60	30.99	650.85

where

A = Fuel Consumption
B = Tyre Consumption (Wear and Tear)
C = Spare Parts Consumption
D = Vehicle Maintenance Labour Hours
E = Crew Cost
F = Vehicle Depreciation
G = Lubricating Oil Consumption
H = Overheads

The user costs for cars and trucks are then shown as column vectors corresponding to states one to seven (expressed in Naira/veh-km), viz:

$$U_{CARS} = \begin{bmatrix} 40.19 \\ 49.02 \\ 79.24 \\ 151.10 \\ 230.55 \\ 266.67 \\ 273.19 \end{bmatrix} ; \quad \text{and} \quad U_{TRUCKS} = \begin{bmatrix} 337.11 \\ 351.78 \\ 409.52 \\ 533.23 \\ 620.22 \\ 646.41 \\ 650.85 \end{bmatrix}$$

where:

U_{CARS} = average user cost column vector for cars (Naira/veh-km)

U_{TRUCKS} = average user cost column vector for trucks(Naira/veh-km)

The weighted mean user cost column vector is then obtained by utilising the percentages of cars and trucks. Given a percentage of cars of 90.4 and that of trucks as 9.6, the weighted mean user cost column vector, U_{WM}, for the case study road was computed as:

$$U_{WM} = \begin{bmatrix} 68.69 \\ 78.08 \\ 110.95 \\ 187.78 \\ 267.96 \\ 303.14 \\ 309.45 \end{bmatrix}$$

3.18 MAINTENANCE INTERVENTION MODELLING

The estimated intervention costs of M&R activities recommended for each state, based on roughness measurement only, are given in Table 3.20.

TABLE 3.20: ESTIMATED COSTS OF M&R ACTIVITIES

Condition State	M&R Strategy	Estimated Cost of M&R Activity ($Nx10^6$/km)
1	No Action	0
2	Routine Maintenance	0.15
3	Preventive Maintenance	0.35
4	Corrective Maintenance	1.0
5	Minor Rehabilitation	3.0
6	Major Rehabilitation	15.0
7	Reconstruction	60

The estimated cost of each M&R activity was based on current rates from Ministry of Transportation (Highways Division). An appropriate inflation rate was incorporated into the costing to make it realistic for the future years of prediction. Thus, a maintenance intervention matrix can be obtained corresponding to different intervention levels, and given as:

$$M_I = \begin{bmatrix} 0.00 \\ 150{,}000.00 \\ 350{,}000.00 \\ 1{,}000{,}000.00 \\ 3{,}000{,}000.00 \\ 15{,}000{,}000.00 \\ 60{,}000{,}000.00 \end{bmatrix}$$

Though an infinite number of maintenance strategies can be evaluated, only three options will be considered in this work, namely:

(i) OPTION 1 – DEFERRED MAINTENANCE

With this option, no form of maintenance intervention is undertaken for the period of study. Thus, the road is left unattended to from year 0 (which would be the beginning year of analysis), till year 20, which is total period covered by this study.

(ii) OPTION 2 – REPAIR FAILED SECTIONS ONLY

Here, due to budget constraint, the emphasis would be to repair only the failed sections (i.e. those in state 7).

(iii) OPTION 3 – REPAIR ALL SECTIONS ANNUALLY

This option considers an ideal situation in which all necessary maintenance is undertaken. The assumption here is that at the end of every year, adequate provision is made for all sections of the road to be taken to the optimum state (i.e. the best state)

3.19 APPLICATION OF USER COSTS ANALYSES TO CASE STUDY ROAD

The initial state vector P_o is obtained by the system, as described in section 4.2.1(a). Next, the appropriate TPM of selected pavement section corresponding to its age and traffic volume is obtained by the system and given as P_{ij}. The different states of the road after the first year are given as:

$$P_1 = P_o * P'_{ij} \tag{3.20}$$

The case study road was surveyed in the year 2005 by PEU. The year when major rehabilitation was carried out on the road was estimated by PEU to be 1999. Hence, the case study road is considered to be six years old (2005-1999) and the traffic volume falls into 5,001–10,000 ADT category. Thus, the system selects TPM B_{ij} and TPM E_{ij} corresponding to the age and traffic volume, computes their average to generate a new TPM P'_{ij}. Thus, P_1 becomes:

$$P_1 = \begin{bmatrix} 0.772908 & 0.227092 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} 0.825 & 0.065 & 0.045 & 0.030 & 0.019 & 0.011 & 0.005 \\ 0 & 0.775 & 0.085 & 0.060 & 0.045 & 0.025 & 0.010 \\ 0 & 0 & 0.775 & 0.090 & 0.070 & 0.040 & 0.025 \\ 0 & 0 & 0 & 0.725 & 0.150 & 0.080 & 0.045 \\ 0 & 0 & 0 & 0 & 0.725 & 0.175 & 0.100 \\ 0 & 0 & 0 & 0 & 0 & 0.675 & 0.325 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1.000 \end{bmatrix} \tag{3.21}$$

P_1 = [0.637   0.226   0.054 0.036   0.024   0.014   0.006]   (3.22)

The weighted mean user cost column vector, $U_{WM} = \begin{bmatrix} 68.69 \\ 78.08 \\ 110.95 \\ 187.78 \\ 267.96 \\ 303.14 \\ 309.45 \end{bmatrix}$

Traffic growth is thus computed as:

$$FT_n = V_o (1+r)^{n-1} \qquad (3.23)$$

where

FT_n = future traffic volume in n years
V_o = initial traffic volume = 9909
r = traffic growth rate = 3%
n = number of years considered = 20

Thus, traffic volume at the end of the first year is given as:

$$FT_1 = 9909 * 365 \text{ days} = 3,616,785 \qquad (3.24)$$

3.19.1 MAINTENANCE OPTION 1 – DEFERRED MAINTENANCE

The basic steps followed in generating the user costs, intervention costs, and total system costs are highlighted in the following sub-sections.

A) USER COST COMPUTATIONS

User cost C_{u1} per kilometre at the end of the first year is given as:

$$C_{u1} = P_1 * U_{WM} * FT_1 \qquad (3.25)$$

$$C_{u1} = [0.637 \quad 0.226 \quad 0.054 \; 0.036 \quad 0.024 \quad 0.014 \quad 0.006] \begin{bmatrix} 68.69 \\ 78.08 \\ 110.95 \\ 187.78 \\ 267.96 \\ 303.14 \\ 309.45 \end{bmatrix} 3,616,785 \qquad (3.26)$$

C_{u1} = N315,497,211.82

Taking into consideration a 15% inflation rate, this becomes C_{u1} = N362,821,793.59.

Similar procedure is followed for the other years of study where:

$C_{u2} = P_2 * U_{WM} * FT_2$ (3.26a)

$C_{u3} = P_3 * U_{WM} * FT_3$, etc. (3.26b)

B) IDEAL INTERVENTION COST COMPUTATIONS

The cost of intervention represents the costs involved in executing maintenance activities. Intervention cost after one year, C_{v1}, is given as:

$C_{v1} = P_1 * M_I$ (3.27)

For the Deferred Maintenance option, no activity is deemed to have taken place and thus intervention cost is zero. However, if M&R activities are to be carried out, these become ideal intervention costs and would be calculated as follows:

$$C_{v1} = [0.637 \quad 0.226 \quad 0.054 \quad 0.036 \quad 0.024 \quad 0.014 \quad 0.006] \begin{bmatrix} 0.00 \\ 150,000.00 \\ 350,000.00 \\ 1,000,000.00 \\ 3,000,000.00 \\ 15,000,000.00 \\ 60,000,000.00 \end{bmatrix} \quad (3.28)$$

C_{v1} = N743,365.00

Taking into consideration a 15% inflation rate, this becomes C_{v1} = N854,869.80.

C) TOTAL SYSTEM COST

The total system cost, C_s is defined as the sum of user cost and intervention cost, i.e.

$C_s = C_u + C_v$ (3.28a)

However, since intervention cost for deferred maintenance is zero (because of no activity), the user costs become the total system cost (see Table 4.5).

3.19.2 MAINTENANCE OPTION 2 – REPAIR FAILED SECTIONS ONLY

Utilizing the initial state vector P_o and the appropriate P_{ij} corresponding to age and traffic volume, the different states of the road after the first year are given as:

$P_1 = P_o * P_{ij}$ (3.29)

$$P_1 = [0.7729 \;\; 0.2271 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0] \begin{bmatrix} 0.825 & 0.065 & 0.045 & 0.030 & 0.019 & 0.011 & 0.005 \\ 0 & 0.775 & 0.085 & 0.060 & 0.045 & 0.025 & 0.010 \\ 0 & 0 & 0.775 & 0.090 & 0.070 & 0.040 & 0.025 \\ 0 & 0 & 0 & 0.725 & 0.150 & 0.080 & 0.045 \\ 0 & 0 & 0 & 0 & 0.725 & 0.175 & 0.100 \\ 0 & 0 & 0 & 0 & 0 & 0.675 & 0.325 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1.000 \end{bmatrix} \quad (3.30)$$

$$P_1 = [0.6377 \;\; 0.2262 \;\; 0.0541 \;\; 0.0368 \;\; 0.0249 \;\; 0.0142 \;\; 0.0061] \quad (3.31)$$

If failed sections only are repaired, then the failed vector value (0.0061) is added to the excellent vector value (0.6377). Thus, the transformed first year state vector becomes:

$$P_1' = [0.6438 \;\; 0.2262 \;\; 0.0541 \;\; 0.0368 \;\; 0.0249 \;\; 0.0142 \;\; 0.0] \quad (3.32)$$

The modified P_1^1 is then used in the computation of the second year state vectors, viz:

P_2 = [0.5150 0.2115 0.0929 0.0687 0.0538 0.0385 0.0196]; and then,

P_2' = [0.5346 0.2115 0.0929 0.0687 0.0538 0.0385 0.0]

The basic steps followed in generating the user costs, intervention costs, and total system costs are highlighted in the following sub-sections.

A) USER COST COMPUTATIONS

User cost C_{u1} per kilometre at the end of the first year is given as:

$$C_{u1} = P_1 * U_{WM} * FT_1 \quad (3.33)$$

$$C_{u1} = [0.6377 \;\; 0.2262 \;\; 0.0541 \;\; 0.0368 \;\; 0.0249 \;\; 0.0142 \;\; 0.0061] \begin{bmatrix} 68.69 \\ 78.08 \\ 110.95 \\ 187.78 \\ 267.96 \\ 303.14 \\ 309.45 \end{bmatrix} 3{,}616{,}785 \quad (3.34)$$

C_{u1} = N315.4972 x 10^6

Taking into consideration a 15% inflation rate, this becomes C_{v1} = N362.82 x 10^6.

For the second year of analysis, FT_2 = 10,206.27*365 = 3,725,288.

$$C_{u2} = P_2' * U_{WM} * FT_2 \quad (3.35)$$

$$P_2 = [0.515 \;\; 0.2115 \;\; 0.0929 \;\; 0.0687 \;\; 0.0538 \;\; 0.0385 \;\; 0.0196] \quad (3.35a)$$

$$C_{u2} = [0.515 \quad 0.2115 \quad 0.0929 \quad 0.0687 \quad 0.0538 \quad 0.0385 \quad 0.0196] \begin{bmatrix} 68.69 \\ 78.08 \\ 110.88 \\ 187.78 \\ 267.95 \\ 303.13 \\ 309.45 \end{bmatrix} 3{,}725{,}288 \qquad (3.36)$$

C_{u2} = N399, 507,123.35

Taking into consideration 15% inflation rate, the users cost per km is C_{u2} =N459,433,191.86 Similar procedure is followed for the remaining years of study.

B) INTERVENTION COST COMPUTATIONS

Here, only the failed sections (represented by the seventh vector of P_1') are repaired. Hence, the actual intervention cost C_{v1} is based on the failed section only. Thus, the intervention cost after one year, $C_{v1,}$ is given as:

$$C_{v1} = P_1' * M_I \qquad (3.37)$$

$$C_{v1} = [0.0 \quad 0.0 \quad 0.0 \quad 0.0 \quad 0.0 \quad 0.0 \quad 0.0061] \begin{bmatrix} 0.00 \\ 150{,}000.00 \\ 350{,}000.00 \\ 1{,}000{,}000.00 \\ 3{,}000{,}000.00 \\ 15{,}000{,}000.00 \\ 60{,}000{,}000.00 \end{bmatrix} \qquad (3.38)$$

C_{v1} = N 366,000.00

Taking into consideration 15% inflation rate, C_{v1} becomes N420,900.00

C) TOTAL SYSTEM COST

The total system cost, C_s is defined as the sum of user cost and intervention cost, i.e.

$$C_s = C_u + C_v \qquad (3.28a)$$

For the first year of analysis, $C_{s1} = C_{u1} + C_{v1}$

$$C_{s1} = N362.82 \times 10^6 + N420{,}900.00 = N363.2427 \times 10^6 \qquad (3.38a)$$

3.19.3 MAINTENANCE OPTION 3 – REPAIR ALL SECTIONS

As for the other previous options, the deterioration profile is calculated first. Thus, after the first year, P_1 is given as:

$$P_1 = [0.7729\ \ 0.2271\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0]\begin{bmatrix} 0.825 & 0.065 & 0.045 & 0.030 & 0.019 & 0.011 & 0.005 \\ 0 & 0.775 & 0.085 & 0.060 & 0.045 & 0.025 & 0.010 \\ 0 & 0 & 0.775 & 0.090 & 0.070 & 0.040 & 0.025 \\ 0 & 0 & 0 & 0.725 & 0.150 & 0.080 & 0.045 \\ 0 & 0 & 0 & 0 & 0.725 & 0.175 & 0.100 \\ 0 & 0 & 0 & 0 & 0 & 0.675 & 0.325 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1.000 \end{bmatrix} \quad (3.39)$$

$$P_1 = [0.6377\quad 0.2262\quad 0.0541\quad 0.0368\quad 0.0249\quad 0.0142\quad 0.0061] \quad (3.40)$$

If all the sections are repaired, then all will upgrade to the excellent state. Thus we have

$$P_1^1 = [1\quad 0.0\quad 0.0\quad 0.0\quad 0.0\quad 0.0\quad 0.0] \quad (3.41)$$

This value of P_1^1 is then used to generate for the second year of analysis, viz:

$$P_2 = [0.8000\quad 0.0650\quad 0.0500\quad 0.0350\quad 0.0250\quad 0.0175\quad 0.0075] \quad (3.42)$$

The basic steps followed in generating the user costs, intervention costs, and total system costs are highlighted in the following sub-sections.

A) USER COST COMPUTATIONS

User cost C_{u1} per kilometre at the end of the first year is given as:

$$C_{u1} = P'_1 * U_{WM} * FT_1 \quad (3.43)$$

$$C_{u1} = [0.6377\quad 0.2262\quad 0.0541\quad 0.0368\quad 0.0249\quad 0.0142\quad 0.0061]\begin{bmatrix} 68.69 \\ 78.08 \\ 110.95 \\ 187.78 \\ 267.96 \\ 303.14 \\ 309.45 \end{bmatrix} 3{,}616{,}785 \quad (3.44)$$

C_{u1} = = N315,497,211.82

After the application of 15% inflation rate, C_{u1} becomes N362,821,793.59.

For the second year of analysis, FT_2 = 10,206.27*365 = 3,725,288.

$$C_{u2} = P_2' * U_{WM} * FT_2 \quad (3.45)$$

$$P_2 = [0.8000\quad 0.0650\quad 0.0500\quad 0.0350\quad 0.0250\quad 0.0175\quad 0.0075] \quad (3.46)$$

$$C_{u2} = [0.8000 \quad 0.0650 \quad 0.0500 \quad 0.0350 \quad 0.0250 \quad 0.0175 \quad 0.0075] \begin{bmatrix} 68.69 \\ 78.08 \\ 110.88 \\ 187.78 \\ 267.95 \\ 303.13 \\ 309.45 \end{bmatrix} 3,725,288 \qquad (3.47)$$

C_{u2} = N322,117,830.26

After the application of 15% inflation rate, C_{u1} becomes N370,435,504.79.
Similar procedure is followed for the other years of study.

B) INTERVENTION COST COMPUTATIONS

Here, all the sections are repaired, bringing them to the excellent state. The intervention cost after one year, $C_{v1,}$ is given as:

$$C_{v1} = P'_1 * M_I \qquad (3.48)$$

$$C_{v1} = [0.637 \quad 0.226 \quad 0.054 \quad 0.036 \quad 0.024 \quad 0.014 \quad 0.006] \begin{bmatrix} 0.00 \\ 150,000.00 \\ 350,000.00 \\ 1,000,000.00 \\ 3,000,000.00 \\ 15,000,000.00 \\ 60,000,000.00 \end{bmatrix} \qquad (3.49)$$

C_{v1} = N743,365.00

After the application of 15% inflation rate, C_{v1} becomes N854, 869.80.

C) TOTAL SYSTEM COST

The total system cost, C_s is defined as the sum of user cost and intervention cost, i.e.

$$C_s = C_u + C_v \qquad (3.28a)$$

$$C_{s1} = N362,821,793.59 + N854,869.80 = N363.6767 \times 10^6 \qquad (3.50)$$

3.20 BENEFIT-COST ANALYSES OF MAINTENANCE INVESTMENTS

In order to justify the costs of intervention activities performed to restore a road, it is useful to calculate the benefit/cost ratio. In this regard, the derived user costs and intervention costs for the ‘Repair Failed Sections Only’ and the ‘Repair All Sections’ options are utilized to obtain the costs and benefits of bringing the different states of a road section to excellent state.

The Benefit /Cost ratios are calculated using the following equation:

$$\frac{\sum_{i=1}^{n} \frac{B_n}{(1+r)^n}}{\sum_{i=1}^{n} \frac{C_n}{(1+r)^n}} \tag{3.51}$$

where

B_n = Benefits in each year
C_n = Intervention cost in each year
n = number of years
r = interest (discount) rate.

$$\text{Discount factor} = \frac{1}{(1+r)^n} \tag{3.52}$$

N.B. The interest (discount) rate is entered at the 'PREDICTION DATA' page (Figure 4.17) as inflation rate.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Manual PCI versus Automated PCI Results for the Selected and Surveyed Road Sections

The procedure in Section 3.3.1 was used to manually calculate the PCI for all the surveyed samples for all the twelve surveyed road sections. Table 4.1 shows the detailed results of twenty-six representatives and two additional samples for Jebba – Mokwa - Kotangora (Section I) road while Table 4.2 shows the summarized section PCI results for the twelve road sections. Thereafter, the developed PIMS was also utilized to calculate the sample and section PCIs for the twelve road sections. The two set of results from manual and automated computations are compared as shown in Tables 4.1 and 4.2.

{The chi-square is computed as below:

$$X^2 = \sum\left[\frac{(Expected - Obtained)^2}{Expected}\right]$$

where:

X^2 = Chi-square
Expected = Manual calculation,
Obtained = Automated calculation (using PIMS)

The degree of freedom is $n = k - 1$, *where k* is the number of categories. Therefore, $n = 28 - 1 = 27$. Using p > **0.9,** the ***p*** value is the probability that the deviation of the observed from that expected is due to chance alone.

Referring to the Chi-square distribution table (Appendix A3), the closest *probability* ***p*** value associated with 15.3984 and 27 degree of freedom is 0.975. This means that there is a 97.5% probability that any deviation from expected results is due to chance only. Based on standard $p > 0.95$, this is within the range of acceptable deviation.

TABLE 4.1: PCI RESULTS FOR THE SURVEYED JEBBA-MOKWA-KOTANGORA (SECTION I) ROAD

SAMPLE No.	TYPE OF SAMPLE	SAMPLE PCI (MANUAL) (A)	AUTOMATED SAMPLE PCI (USING PIMS) (B)	DIFFERENCE (D=A-B)	D^2	D^2/A
1	Representative	45.0	45.54	-0.54	0.2916	0.0065
2	Representative	44.2	45.15	-0.95	0.9025	0.0204
3	Representative	70.0	70.00	0	0	0.0000
4	Representative	62.0	62.63	-0.63	0.3969	0.0064
5	Representative	87.0	86.25	0.75	0.5625	0.0065
6	Representative	28.0	29.17	-1.17	1.3689	0.0489
7	Representative	45.0	45.31	-0.31	0.0961	0.0021
8	Representative	39.5	38.97	0.53	0.2809	0.0071
9	Representative	41.0	40.93	0.07	0.0049	0.0001
10	Representative	25.5	27.05	-1.55	2.4025	0.0942
11	Representative	67.0	67.99	-0.99	0.9801	0.0146
12	Representative	27.0	40.05	-13.05	170.3025	6.3075
13	Representative	34.5	35.14	-0.64	0.4096	0.0119
14	Representative	36.0	37.17	-1.17	1.3689	0.0380
15	Representative	32.0	48.21	-16.21	262.7641	8.2114
16	Representative	88.0	88.99	-0.99	0.9801	0.0111
17	Representative	58.0	59.17	-1.17	1.3689	0.0236
18	Representative	28.0	30.23	-2.23	4.9729	0.1776
19	Representative	76.0	77.82	-1.82	3.3124	0.0436
20	Representative	67.0	66.67	0.33	0.1089	0.0016
21	Representative	28.0	29.03	-1.03	1.0609	0.0379
22	Representative	24.0	23.97	0.03	0.0009	0.0000
23	Representative	53.0	52.86	0.14	0.0196	0.0004
24	Representative	32.0	30.31	1.69	2.8561	0.0893
25	Representative	72.0	71.85	0.15	0.0225	0.0003
26	Representative	59.0	57.50	1.5	2.25	0.0381
27	Additional	23.0	22.24	0.76	0.5776	0.0251
28	Additional	8.0	9.18	-1.18	1.3924	0.1741
	Section PCI	48.0	47.83		**SUM =**	**15.3984**
	Mean	46.0	48	**Chi-square X^2 = 15.3984**		
	Std Deviation	21.1	20.47			
	C.O.V*	0.5	0.4			

*Coefficient of Variation (C.O.V) = Standard Deviation / Mean

TABLE 4.2: PCI RESULTS FOR THE TWELVE SELECTED AND SURVEYED ROAD SECTIONS

S/No.	DESCRIPTION	SECTION PCI (MANUAL)	AUTOMATED SECTION PCI (USING PIMS)	DIFF. (D=A-B)	D^2	D^2/A
1	Jebba – Mokwa- Kotangora Road (Section I)	48.0	47.83	0.17	0.0289	0.000602
2	Mokwa – Makera Road	55.0	54.24	0.76	0.5776	0.010502
3	Makera – Kasanga Road	49.0	49.35	-0.35	0.1225	0.0025
4	Kasanga – Tegina Road	58.0	57.46	0.54	0.2916	0.005028
5	Tegina – Ikerebodo Road	66.0	65.85	0.15	0.0225	0.000341
6	Ikerebodo – Birnin Gwari Road	64.0	63.48	0.52	0.2704	0.004225
7	Egbe – Omu Aran Road	35.0	36.25	-1.25	1.5625	0.044643
8	Ajaokuta – Adumu Road	37.0	36.67	0.33	0.1089	0.002943
9	Adumu – Ayingba Road	40.0	41.05	-1.05	1.1025	0.027562
10	Maje – Suleja – Madalla Road	56.0	55.25	0.75	0.5625	0.010045
11	Tegina – Zungeru Road	53.0	52.36	0.64	0.4096	0.007728
12	Zungeru – Minna Road	62.0	61.34	0.66	0.4356	0.007026
	MEAN	52.0	52.0		**SUM =**	**0.123145**
	Standard Deviation	10.4	9.9	**Chi-square X^2 = 0.123145**		
	C.O.V*	0.2	0.2			

*Coefficient of Variation (C.O.V) = Standard Deviation / Mean

RESULTS OF BOTH MANUAL AND AUTOMATED COMPUTATIONS FOR THE TWELVE (SURVEYED) ROADS (Table 4.2)

The degree of freedom is 11, i.e., *n=k-1*. Using p > **0.95**, and referring to the Chi-square distribution table, the closest *probability* value *associated* with 0.123145 and 11 degree of freedom is 0.995. This means that there is a 99.5% probability that any deviation from expected results is due to chance only. Based on standard *p > 0.95*, this is within the range of acceptable deviation}.

Comparison of the two sets of results using coefficient of variation and chi-square shows that the developed PIMS can reliably generate PCI results for surveyed roads. This fact is also attested to by the comparison of the section PCI results for the other eleven road sections that were surveyed.

4.2 AUTOMATED PCI COMPUTATION RESULTS

The developed PIMS can be used to quickly and easily compute PCI results for any surveyed highway section.

a. **Results Display:** Clicking the "RESULT" button (Fig. 3.12) displays the final results for all samples keyed in. It opens the result page (Figure 4.1) which provides the Section PCI value, PCI category and the standard deviation value. M&R Strategy is automatically recommended based on the generated section PCI (see Table 4.3). A corresponding M&R cost is also automatically provided for the generated strategy based on the values previously provided by the user. This result page also provides a listing of all the samples considered in the PCI calculations. Finally, the user has the option to print the output directly or save to file for later printing

TABLE 4.3: M&R STRATEGIES AND CORRESPONDING ESTIMATED COSTS

Section PCI Range	M&R Strategy	Estimated Cost of M&R Activity / km ($Nx10^6$)
95-100	No Action	0
86 – 95	Routine Maintenance	2.5
71 – 85	Preventive Maintenance	4.0
56 – 70	Corrective Maintenance	6.0
46 – 55	Minor Rehabilitation	8.5
26 – 45	Major Rehabilitation	11.0
0 – 25	Reconstruction	20

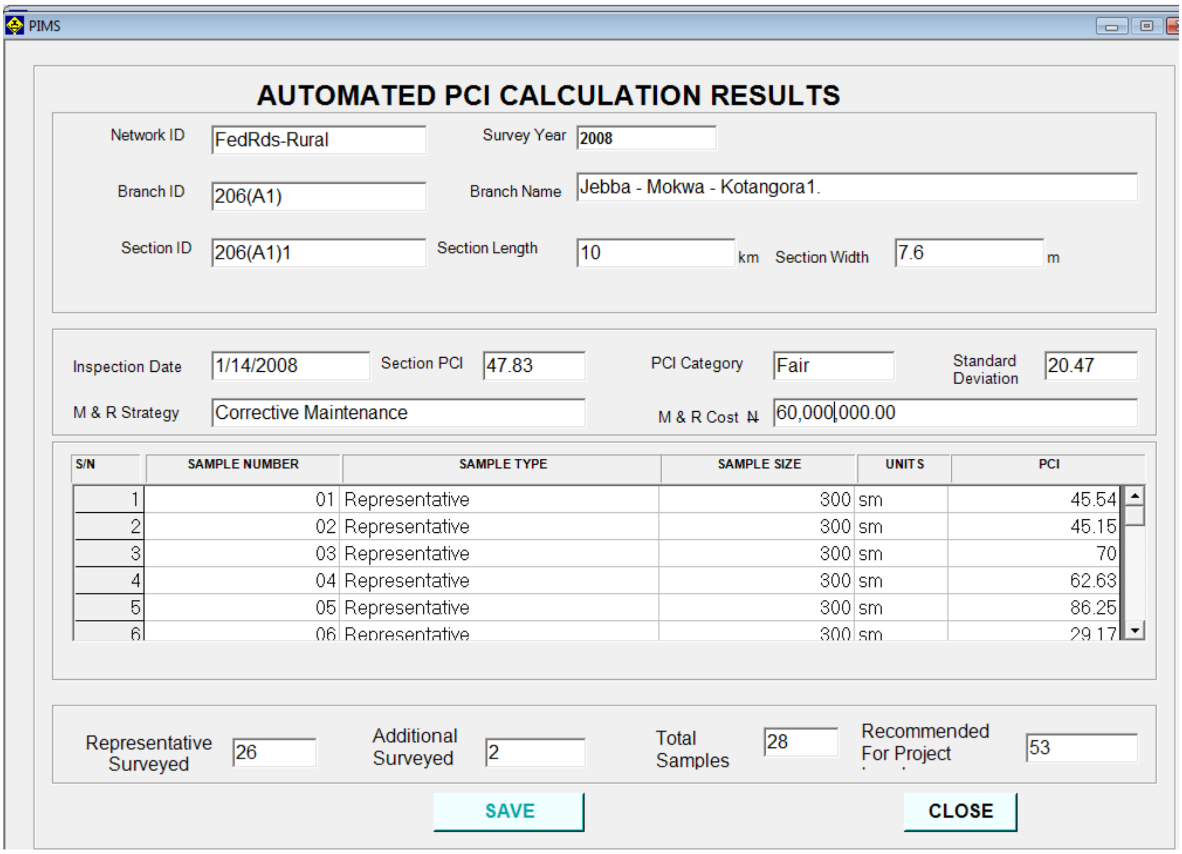


Figure 4.1: Automated PCI Calculation Results Page

b. Distress Image/Video Log: Selection of either of "Distress Images" or "Video Log" buttons opens the page where images and video log of distresses captured on site can be viewed (Figure 4.2).

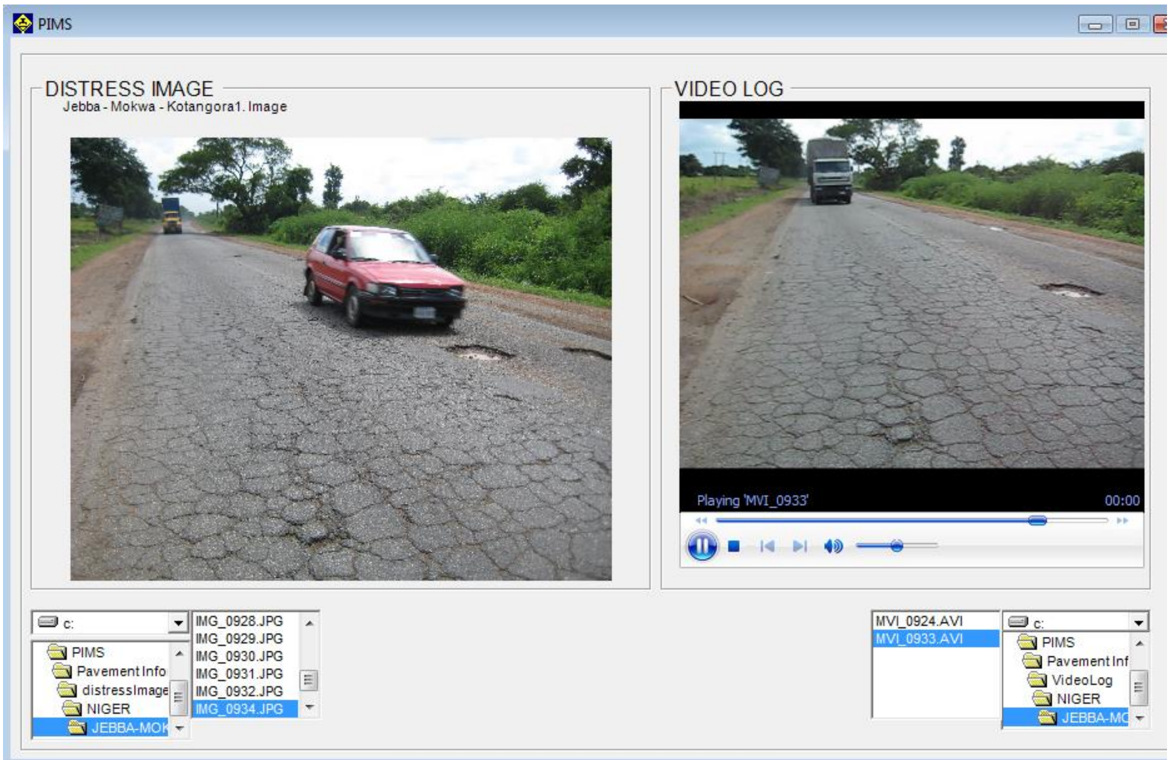


Figure 4.2: Display of Images and Videolog of Distresses Captured on Site

4.3 GENERATING CONDITION REPORTS

The developed PIMS system is also capable of generating a series of condition reports that are useful to aid decision-makers in evaluating both the condition of individual road section and the overall condition of the entire network. The three condition reports that can be generated for all the pavements at the network level are Section Condition Report, Branch Condition Report and Historic Report. The Section and Branch condition reports can be accessed from the "REPORT" menu bar (Figure 4.3).

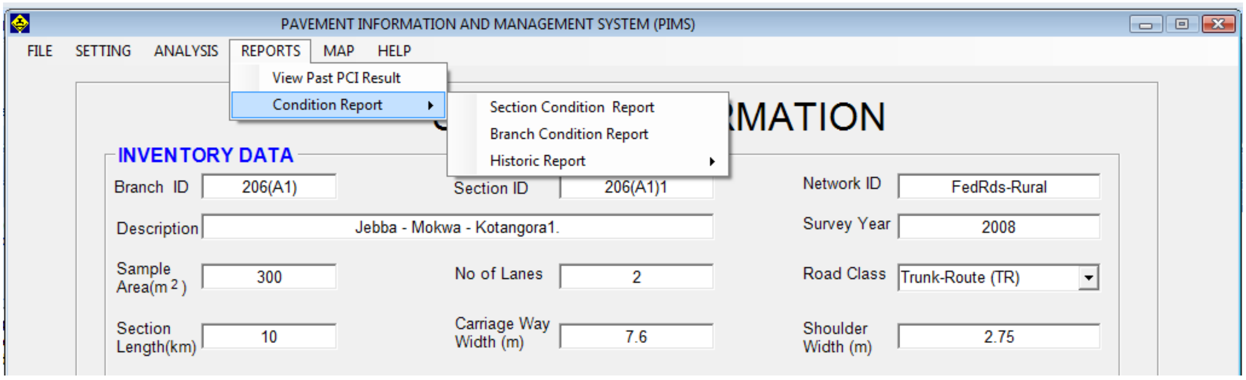


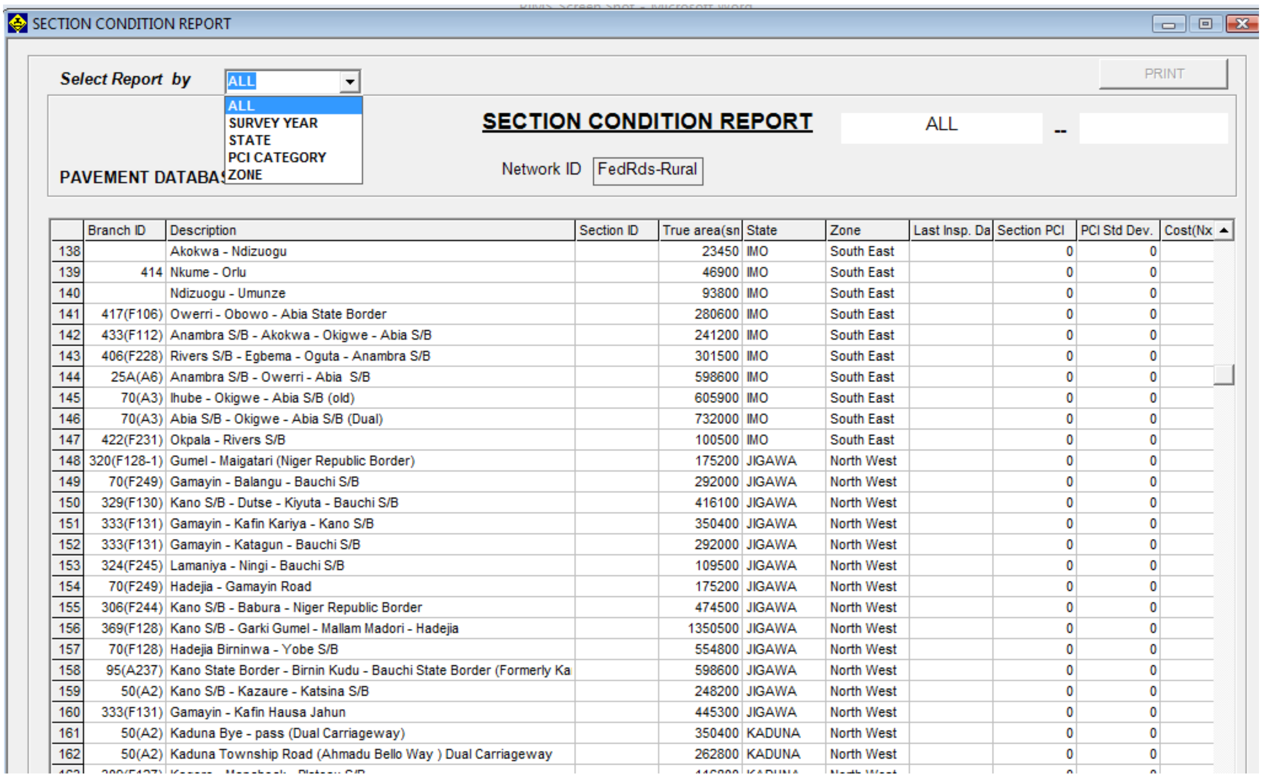
Figure 4.3: Accessing the Condition Report Module

A) Section Condition Reporting

The Section Condition Report is designed to contain all the basic information pertinent to the section(s) of all related branches in the road network such as the state, zone, and last inspection date. It also provides detailed information concerning the condition (average PCI), PCI Standard Deviation, M&R Cost and PCI Category. Reports could be displayed for the following categories:

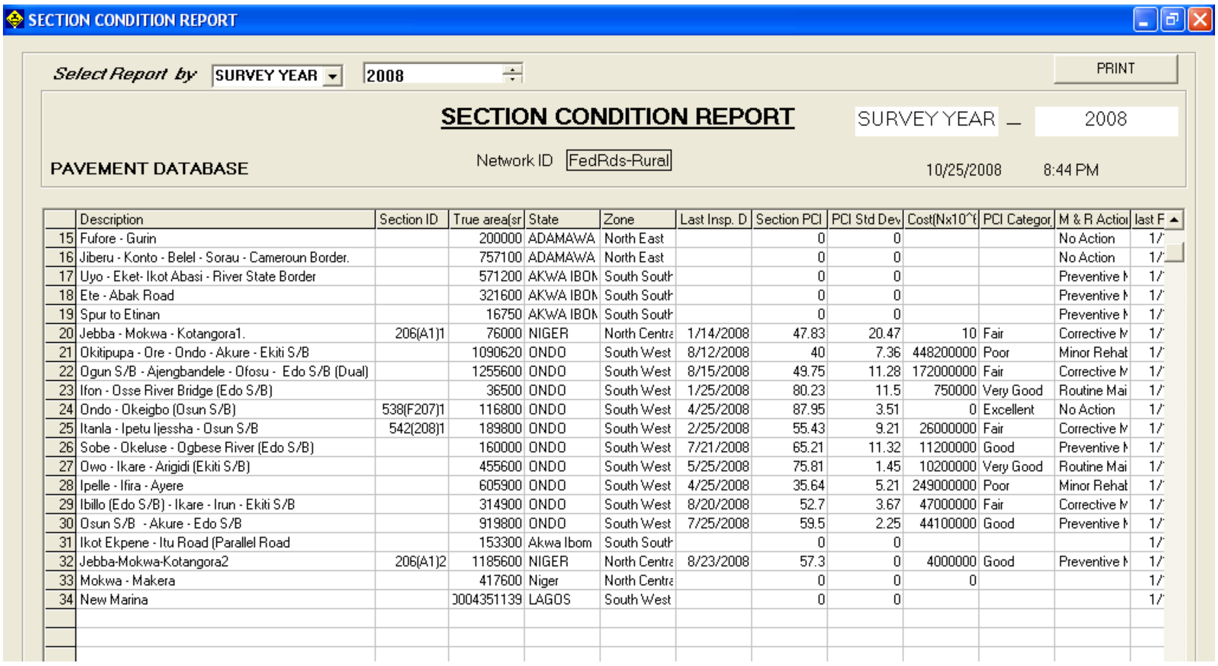
- **ALL**: If this option is selected, all the roads in the network (and database) are loaded up and listed (Figure 4.4).
- **Survey Year**: A particular year is selected by the user and the results for all the roads surveyed in the selected year are listed (Figure 4.5).
- **State:** With this option, the user can view the results for roads surveyed in any state of the federation (Figure 4.6).
- **PCI Category:** If the user wishes to view reports on roads in the network according to PCI category, this option is selected (Figure 4.7).
- **Zone:** This option displays results for surveyed roads for a selected geopolitical zone in the country (Figure 4.8).

N.B. For any category of report selected, the user can print hard copy by clicking on the "Print" tab in the upper right corner of the interfaces.



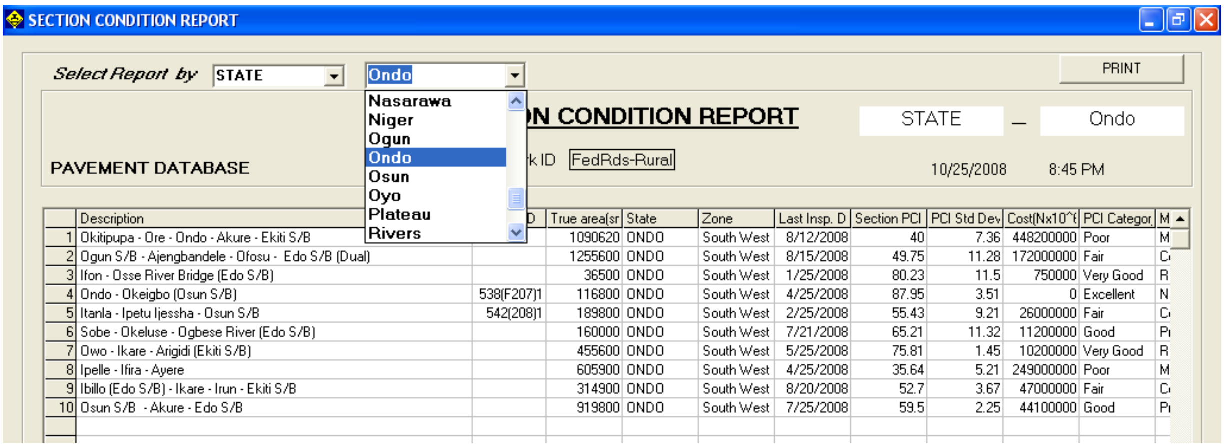
	Branch ID	Description	Section ID	True area(sn	State	Zone	Last Insp. Da	Section PCI	PCI Std Dev.	Cost(Nx
138		Akokwa - Ndizuogu		23450	IMO	South East		0	0	
139	414	Nkume - Orlu		46900	IMO	South East		0	0	
140		Ndizuogu - Umunze		93800	IMO	South East		0	0	
141	417(F106)	Owerri - Obowo - Abia State Border		280600	IMO	South East		0	0	
142	433(F112)	Anambra S/B - Akokwa - Okigwe - Abia S/B		241200	IMO	South East		0	0	
143	406(F228)	Rivers S/B - Egbema - Oguta - Anambra S/B		301500	IMO	South East		0	0	
144	25A(A6)	Anambra S/B - Owerri - Abia S/B		598600	IMO	South East		0	0	
145	70(A3)	Ihube - Okigwe - Abia S/B (old)		605900	IMO	South East		0	0	
146	70(A3)	Abia S/B - Okigwe - Abia S/B (Dual)		732000	IMO	South East		0	0	
147	422(F231)	Okpala - Rivers S/B		100500	IMO	South East		0	0	
148	320(F128-1)	Gumel - Maigatari (Niger Republic Border)		175200	JIGAWA	North West		0	0	
149	70(F249)	Gamayin - Balangu - Bauchi S/B		292000	JIGAWA	North West		0	0	
150	329(F130)	Kano S/B - Dutse - Kiyuta - Bauchi S/B		416100	JIGAWA	North West		0	0	
151	333(F131)	Gamayin - Kafin Kariya - Kano S/B		350400	JIGAWA	North West		0	0	
152	333(F131)	Gamayin - Katagun - Bauchi S/B		292000	JIGAWA	North West		0	0	
153	324(F245)	Lamaniya - Ningi - Bauchi S/B		109500	JIGAWA	North West		0	0	
154	70(F249)	Hadejia - Gamayin Road		175200	JIGAWA	North West		0	0	
155	306(F244)	Kano S/B - Babura - Niger Republic Border		474500	JIGAWA	North West		0	0	
156	369(F128)	Kano S/B - Garki Gumel - Mallam Madori - Hadejia		1350500	JIGAWA	North West		0	0	
157	70(F128)	Hadejia Birninwa - Yobe S/B		554800	JIGAWA	North West		0	0	
158	95(A237)	Kano State Border - Birnin Kudu - Bauchi State Border (Formerly Ka		598600	JIGAWA	North West		0	0	
159	50(A2)	Kano S/B - Kazaure - Katsina S/B		248200	JIGAWA	North West		0	0	
160	333(F131)	Gamayin - Kafin Hausa Jahun		445300	JIGAWA	North West		0	0	
161	50(A2)	Kaduna Bye - pass (Dual Carriageway)		350400	KADUNA	North West		0	0	
162	50(A2)	Kaduna Township Road (Ahmadu Bello Way) Dual Carriageway		262800	KADUNA	North West		0	0	

Figure 4.4: Section Condition Report Interface for All Roads in the Network



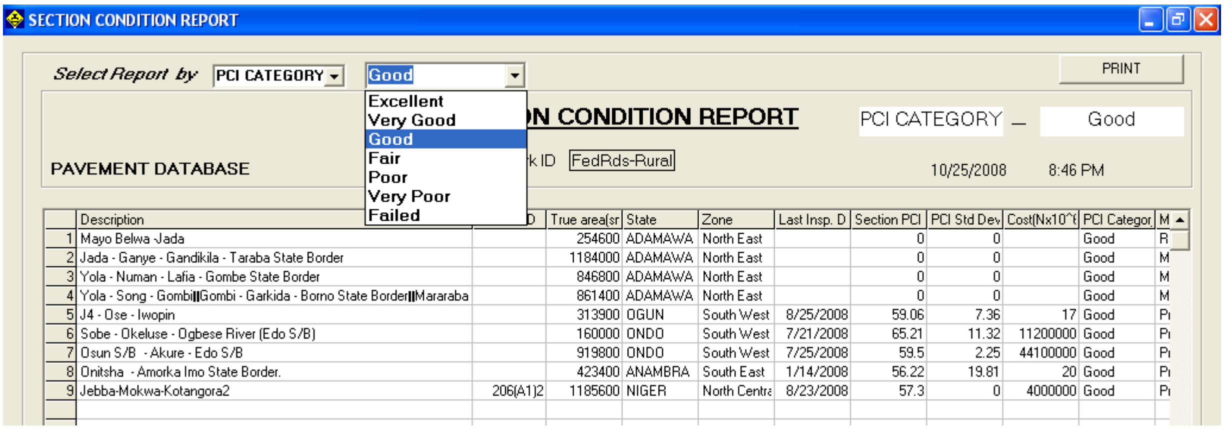
	Description	Section ID	True area(sr	State	Zone	Last Insp. D	Section PCI	PCI Std Dev	Cost(Nx10^(	PCI Categor	M & R Actio	last F
15	Fufore - Gurin		200000	ADAMAWA	North East		0	0			No Action	1/
16	Jiberu - Konto - Belel - Sorau - Cameroun Border.		757100	ADAMAWA	North East		0	0			No Action	1/
17	Uyo - Eket- Ikot Abasi - River State Border		571200	AKWA IBON	South South		0	0			Preventive N	1/
18	Ete - Abak Road		321600	AKWA IBON	South South		0	0			Preventive N	1/
19	Spur to Etinan		16750	AKWA IBON	South South		0	0			Preventive N	1/
20	Jebba - Mokwa - Kotangora1.	206(A1)1	76000	NIGER	North Centra	1/14/2008	47.83	20.47	10	Fair	Corrective M	1/
21	Okitipupa - Ore - Ondo - Akure - Ekiti S/B		1090620	ONDO	South West	8/12/2008	40	7.36	448200000	Poor	Minor Rehab	1/
22	Ogun S/B - Ajengbandele - Ofosu - Edo S/B (Dual)		1255600	ONDO	South West	8/15/2008	49.75	11.28	172000000	Fair	Corrective M	1/
23	Ifon - Osse River Bridge (Edo S/B)		36500	ONDO	South West	1/25/2008	80.23	11.5	750000	Very Good	Routine Mai	1/
24	Ondo - Okeigbo (Osun S/B)	538(F207)1	116800	ONDO	South West	4/25/2008	87.95	3.51	0	Excellent	No Action	1/
25	Itanla - Ipetu Ijessha - Osun S/B	542(208)1	189800	ONDO	South West	2/25/2008	55.43	9.21	26000000	Fair	Corrective M	1/
26	Sobe - Okeluse - Ogbese River (Edo S/B)		160000	ONDO	South West	7/21/2008	65.21	11.32	11200000	Good	Preventive N	1/
27	Owo - Ikare - Arigidi (Ekiti S/B)		455600	ONDO	South West	5/25/2008	75.81	1.45	10200000	Very Good	Routine Mai	1/
28	Ipelle - Ifira - Ayere		605900	ONDO	South West	4/25/2008	35.64	5.21	249000000	Poor	Minor Rehab	1/
29	Ibillo (Edo S/B) - Ikare - Irun - Ekiti S/B		314900	ONDO	South West	8/20/2008	52.7	3.67	47000000	Fair	Corrective M	1/
30	Osun S/B - Akure - Edo S/B		919800	ONDO	South West	7/25/2008	59.5	2.25	44100000	Good	Preventive N	1/
31	Ikot Ekpene - Itu Road (Parallel Road		153300	Akwa Ibom	South South		0	0				1/
32	Jebba-Mokwa-Kotangora2	206(A1)2	1185600	NIGER	North Centra	8/23/2008	57.3	0	4000000	Good	Preventive N	1/
33	Mokwa - Makera		417600	Niger	North Centra		0	0	0			1/
34	New Marina		)004351139	LAGOS	South West		0	0				1/

Figure 4.5: Section Condition Report for Roads Surveyed in a Selected Year



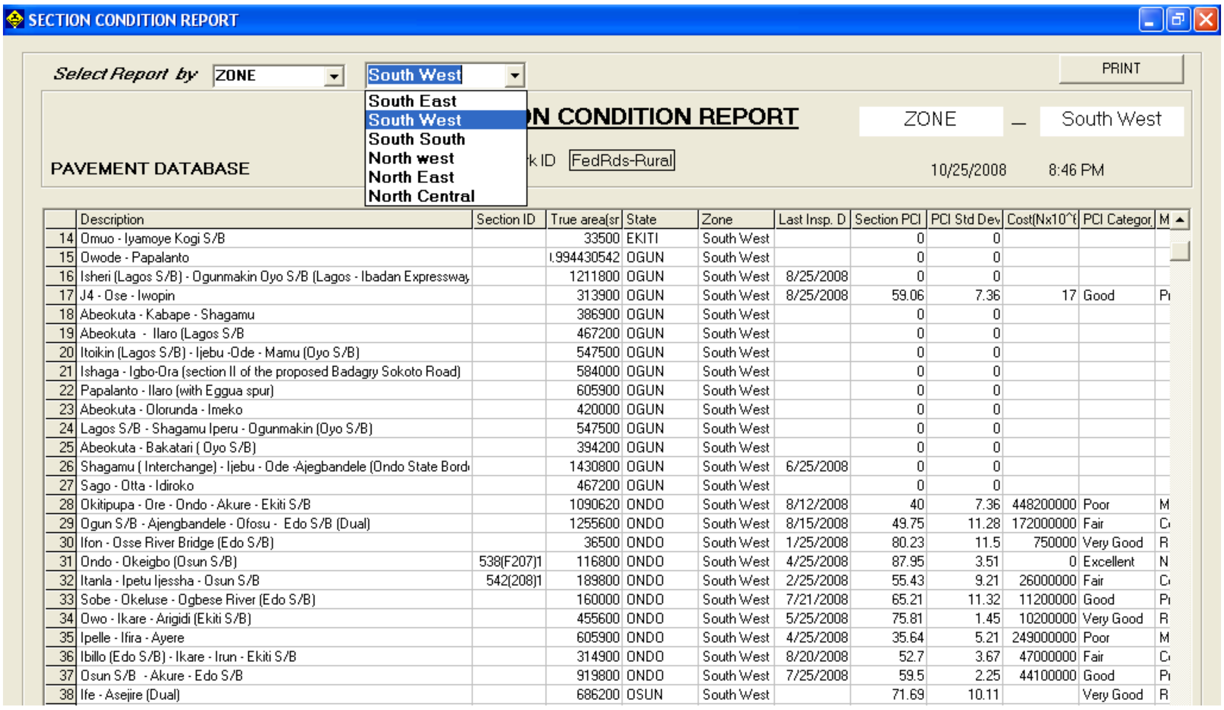
	Description	D	True area(sr	State	Zone	Last Insp. D	Section PCI	PCI Std Dev	Cost(Nx10^(	PCI Categor	M
1	Okitipupa - Ore - Ondo - Akure - Ekiti S/B		1090620	ONDO	South West	8/12/2008	40	7.36	448200000	Poor	M
2	Ogun S/B - Ajengbandele - Ofosu - Edo S/B (Dual)		1255600	ONDO	South West	8/15/2008	49.75	11.28	172000000	Fair	C
3	Ifon - Osse River Bridge (Edo S/B)		36500	ONDO	South West	1/25/2008	80.23	11.5	750000	Very Good	R
4	Ondo - Okeigbo (Osun S/B)	538(F207)1	116800	ONDO	South West	4/25/2008	87.95	3.51	0	Excellent	N
5	Itanla - Ipetu Ijessha - Osun S/B	542(208)1	189800	ONDO	South West	2/25/2008	55.43	9.21	26000000	Fair	C
6	Sobe - Okeluse - Ogbese River (Edo S/B)		160000	ONDO	South West	7/21/2008	65.21	11.32	11200000	Good	P
7	Owo - Ikare - Arigidi (Ekiti S/B)		455600	ONDO	South West	5/25/2008	75.81	1.45	10200000	Very Good	R
8	Ipelle - Ifira - Ayere		605900	ONDO	South West	4/25/2008	35.64	5.21	249000000	Poor	M
9	Ibillo (Edo S/B) - Ikare - Irun - Ekiti S/B		314900	ONDO	South West	8/20/2008	52.7	3.67	47000000	Fair	C
10	Osun S/B - Akure - Edo S/B		919800	ONDO	South West	7/25/2008	59.5	2.25	44100000	Good	P

Figure 4.6: Section Condition Report for Roads Surveyed in a Selected State of the Federation



	Description	D	True area(sr	State	Zone	Last Insp. D	Section PCI	PCI Std Dev	Cost(Nx10^(	PCI Categor	M
1	Mayo Belwa -Jada		254600	ADAMAWA	North East		0	0		Good	R
2	Jada - Ganye - Gandikila - Taraba State Border		1184000	ADAMAWA	North East		0	0		Good	M
3	Yola - Numan - Lafia - Gombe State Border		846800	ADAMAWA	North East		0	0		Good	M
4	Yola - Song - Gombi‖Gombi - Garkida - Borno State Border‖Mararaba		861400	ADAMAWA	North East		0	0		Good	M
5	J4 - Ose - Iwopin		313900	OGUN	South West	8/25/2008	59.06	7.36	17	Good	P
6	Sobe - Okeluse - Ogbese River (Edo S/B)		160000	ONDO	South West	7/21/2008	65.21	11.32	11200000	Good	P
7	Osun S/B - Akure - Edo S/B		919800	ONDO	South West	7/25/2008	59.5	2.25	44100000	Good	P
8	Onitsha - Amorka Imo State Border.		423400	ANAMBRA	South East	1/14/2008	56.22	19.81	20	Good	P
9	Jebba-Mokwa-Kotangora2	206(A1)2	1185600	NIGER	North Centra	8/23/2008	57.3	0	4000000	Good	P

Figure 4.7: Section Condition Report for Roads Surveyed According to PCI Category



SECTION CONDITION REPORT

Select Report by ZONE | South West | PRINT

South East
South West
South South
North west
North East
North Central

PAVEMENT DATABASE

N CONDITION REPORT | ZONE — South West

k ID FedRds-Rural

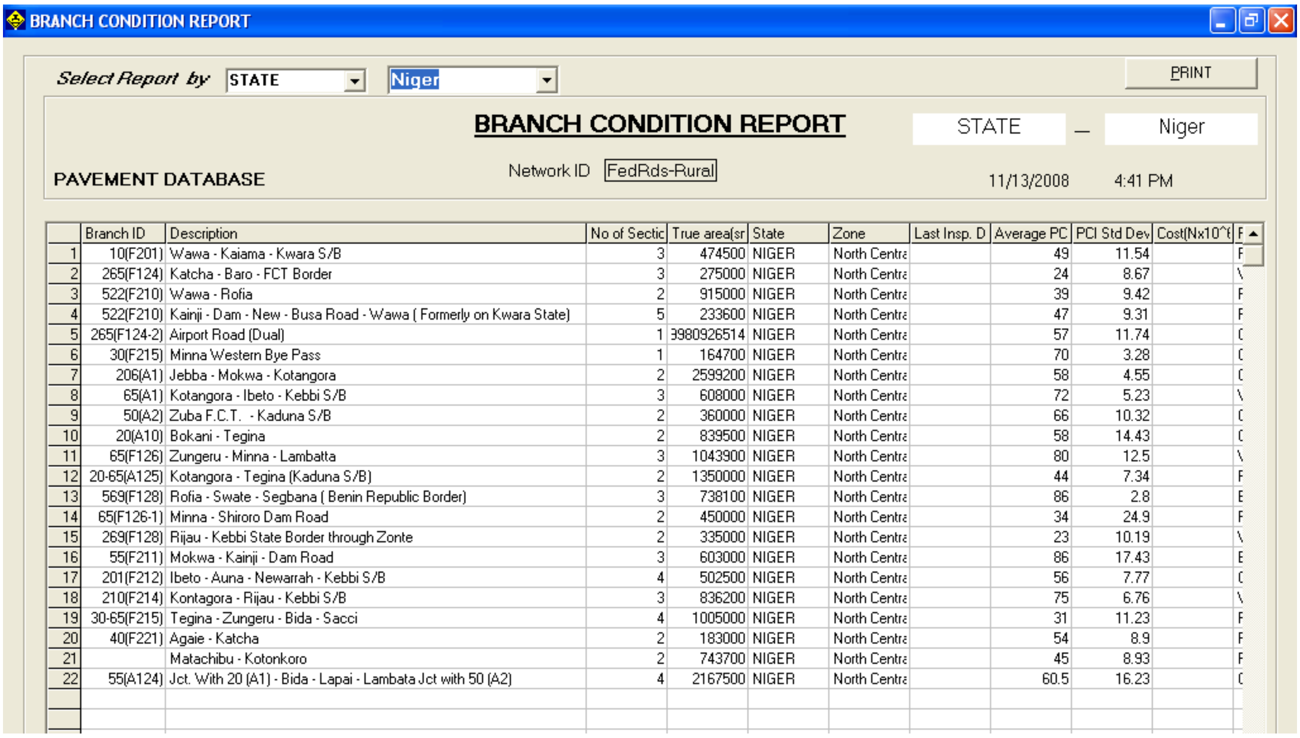
10/25/2008 8:46 PM

	Description	Section ID	True area(sr	State	Zone	Last Insp. D	Section PCI	PCI Std Dev	Cost(Nx10^	PCI Categor	M
14	Omuo - Iyamoye Kogi S/B		33500	EKITI	South West		0	0			
15	Owode - Papalanto		1.994430542	OGUN	South West		0	0			
16	Isheri (Lagos S/B) - Ogunmakin Oyo S/B (Lagos - Ibadan Expressway		1211800	OGUN	South West	8/25/2008	0	0			
17	J4 - Ose - Iwopin		313900	OGUN	South West	8/25/2008	59.06	7.36	17	Good	P
18	Abeokuta - Kabape - Shagamu		386900	OGUN	South West		0	0			
19	Abeokuta - Ilaro (Lagos S/B		467200	OGUN	South West		0	0			
20	Itoikin (Lagos S/B) - Ijebu -Ode - Mamu (Oyo S/B)		547500	OGUN	South West		0	0			
21	Ishaga - Igbo-Ora (section II of the proposed Badagry Sokoto Road)		584000	OGUN	South West		0	0			
22	Papalanto - Ilaro (with Eggua spur)		605900	OGUN	South West		0	0			
23	Abeokuta - Olorunda - Imeko		420000	OGUN	South West		0	0			
24	Lagos S/B - Shagamu Iperu - Ogunmakin (Oyo S/B)		547500	OGUN	South West		0	0			
25	Abeokuta - Bakatari (Oyo S/B)		394200	OGUN	South West		0	0			
26	Shagamu (Interchange) - Ijebu - Ode -Ajegbandele (Ondo State Bord		1430800	OGUN	South West	6/25/2008	0	0			
27	Sago - Otta - Idiroko		467200	OGUN	South West		0	0			
28	Okitipupa - Ore - Ondo - Akure - Ekiti S/B		1090620	ONDO	South West	8/12/2008	40	7.36	448200000	Poor	M
29	Ogun S/B - Ajengbandele - Ofosu - Edo S/B (Dual)		1255600	ONDO	South West	8/15/2008	49.75	11.28	172000000	Fair	C
30	Ifon - Osse River Bridge (Edo S/B)		36500	ONDO	South West	1/25/2008	80.23	11.5	750000	Very Good	R
31	Ondo - Okeigbo (Osun S/B)	538(F207)1	116800	ONDO	South West	4/25/2008	87.95	3.51	0	Excellent	N
32	Itanla - Ipetu Ijessha - Osun S/B	542(208)1	189800	ONDO	South West	2/25/2008	55.43	9.21	26000000	Fair	C
33	Sobe - Okeluse - Ogbese River (Edo S/B)		160000	ONDO	South West	7/21/2008	65.21	11.32	11200000	Good	P
34	Owo - Ikare - Arigidi (Ekiti S/B)		455600	ONDO	South West	5/25/2008	75.81	1.45	10200000	Very Good	R
35	Ipelle - Ifira - Ayere		605900	ONDO	South West	4/25/2008	35.64	5.21	249000000	Poor	M
36	Ibillo (Edo S/B) - Ikare - Irun - Ekiti S/B		314900	ONDO	South West	8/20/2008	52.7	3.67	47000000	Fair	C
37	Osun S/B - Akure - Edo S/B		919800	ONDO	South West	7/25/2008	59.5	2.25	44100000	Good	P
38	Ife - Asejire (Dual)		686200	OSUN	South West		71.69	10.11		Very Good	R

Figure 4.8: Section Condition Report for Roads Surveyed According to Geopolitical Zone

B) Branch Condition Reporting

Branch Condition reporting is very much similar to Section Condition reporting. The major difference is that branch reporting is an aggregated summary of the individual reports of the various sections that make up a branch. Figure 4.9 is an example of the display of branch condition report according to state category.



BRANCH CONDITION REPORT

Select Report by STATE | Niger | PRINT

BRANCH CONDITION REPORT | STATE — Niger

PAVEMENT DATABASE

Network ID FedRds-Rural

11/13/2008 4:41 PM

	Branch ID	Description	No of Sectic	True area(sr	State	Zone	Last Insp. D	Average PC	PCI Std Dev	Cost(Nx10^	F
1	10(F201)	Wawa - Kaiama - Kwara S/B	3	474500	NIGER	North Centra		49	11.54		F
2	265(F124)	Katcha - Baro - FCT Border	3	275000	NIGER	North Centra		24	8.67		V
3	522(F210)	Wawa - Rofia	2	915000	NIGER	North Centra		39	9.42		F
4	522(F210)	Kainji - Dam - New - Busa Road - Wawa (Formerly on Kwara State)	5	233600	NIGER	North Centra		47	9.31		F
5	265(F124-2)	Airport Road (Dual)	1	3980926514	NIGER	North Centra		57	11.74		C
6	30(F215)	Minna Western Bye Pass	1	164700	NIGER	North Centra		70	3.28		C
7	206(A1)	Jebba - Mokwa - Kotangora	2	2599200	NIGER	North Centra		58	4.55		C
8	65(A1)	Kotangora - Ibeto - Kebbi S/B	3	608000	NIGER	North Centra		72	5.23		V
9	50(A2)	Zuba F.C.T. - Kaduna S/B	2	360000	NIGER	North Centra		66	10.32		C
10	20(A10)	Bokani - Tegina	2	839500	NIGER	North Centra		58	14.43		C
11	65(F126)	Zungeru - Minna - Lambatta	3	1043900	NIGER	North Centra		80	12.5		V
12	20-65(A125)	Kotangora - Tegina (Kaduna S/B)	2	1350000	NIGER	North Centra		44	7.34		F
13	569(F128)	Rofia - Swate - Segbana (Benin Republic Border)	3	738100	NIGER	North Centra		86	2.8		E
14	65(F126-1)	Minna - Shiroro Dam Road	2	450000	NIGER	North Centra		34	24.9		F
15	269(F128)	Rijau - Kebbi State Border through Zonte	2	335000	NIGER	North Centra		23	10.19		V
16	55(F211)	Mokwa - Kainji - Dam Road	3	603000	NIGER	North Centra		86	17.43		E
17	201(F212)	Ibeto - Auna - Newarrah - Kebbi S/B	4	502500	NIGER	North Centra		56	7.77		C
18	210(F214)	Kontagora - Rijau - Kebbi S/B	3	836200	NIGER	North Centra		75	6.76		V
19	30-65(F215)	Tegina - Zungeru - Bida - Sacci	4	1005000	NIGER	North Centra		31	11.23		F
20	40(F221)	Agaie - Katcha	2	183000	NIGER	North Centra		54	8.9		F
21		Matachibu - Kotonkoro	2	743700	NIGER	North Centra		45	8.93		F
22	55(A124)	Jct. With 20 (A1) - Bida - Lapai - Lambata Jct with 50 (A2)	4	2167500	NIGER	North Centra		60.5	16.23		C

Figure 4.9: Branch Condition Report for a Selected State

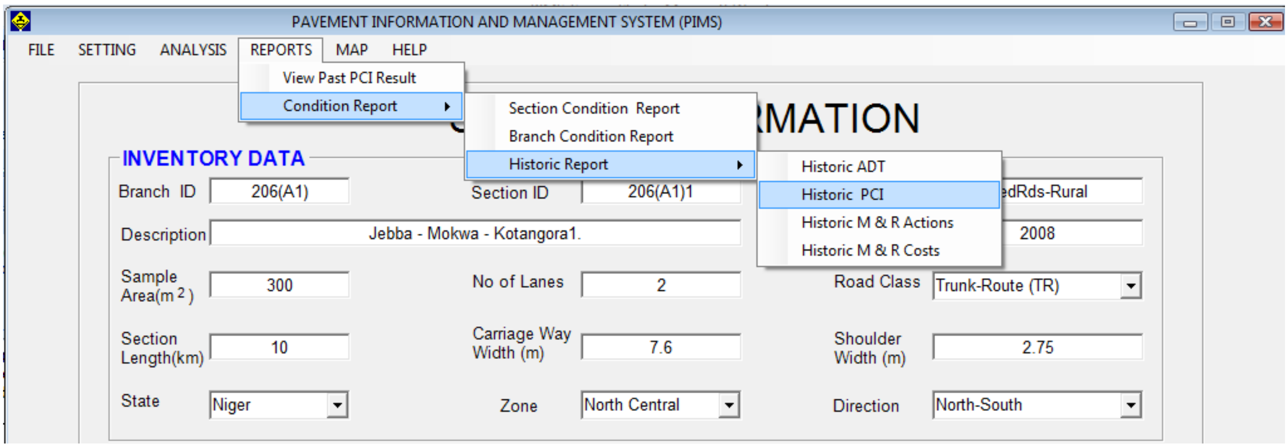


Figure 4.10: Accessing the Historic Information Module

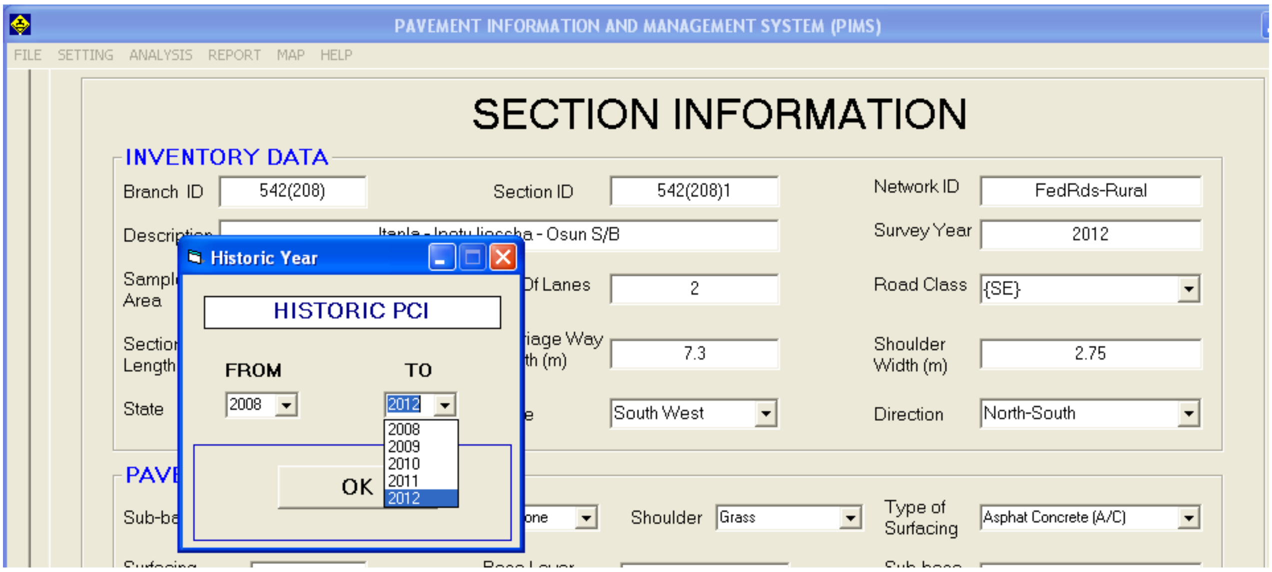


Figure 4.11: Selection of the Range of Years for Historic PCI Report Display

C) Historic Condition Reporting

Finally, the developed PIMS is capable of displaying historic reports for some key parameters such as ADT, PCI, M&R Actions and Costs. The user selects any of the listed parameters from the 'Historic Reports' submenu (Figure 4.10). Thereafter, the user is prompted to select the range of years for which result is being sought (Figure 4.11).

The PIMS subsequently plots and displays a graph of the stored values for the selected parameter, for the range of years selected. Figures 4.12, 4.13, 4.14 and 4.15 show the results of the historic data of ADT, PCI, M&R Actions and Costs respectively, from the year 2008 to 2020.

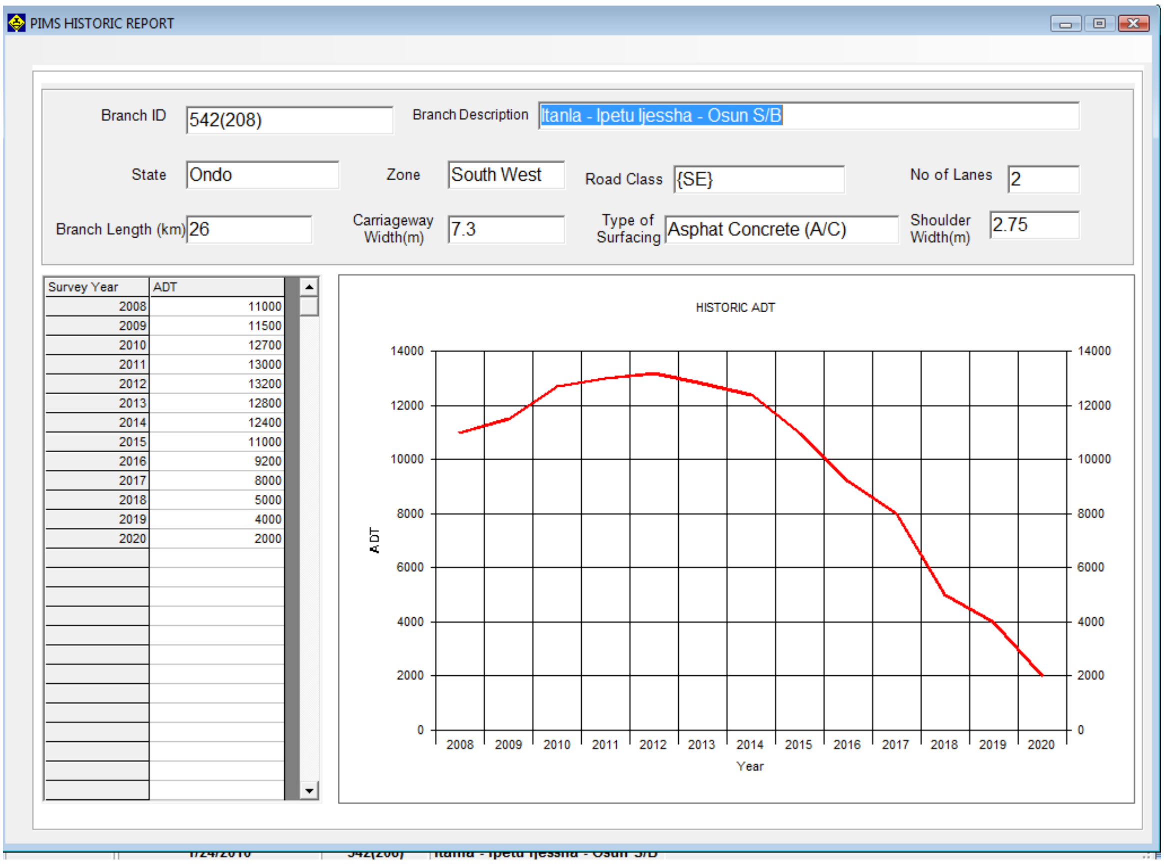


Figure 4.12: Historic ADT Report Display for a Selected Road and Range of Years

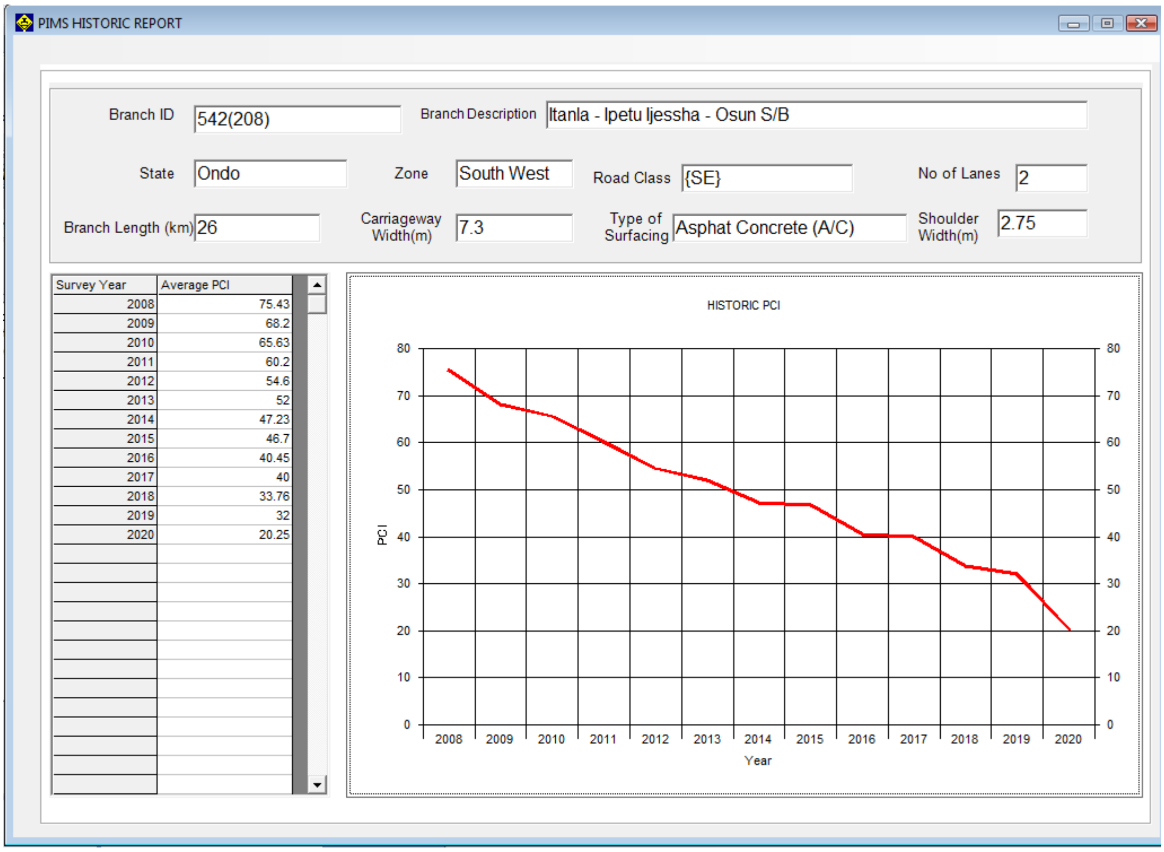
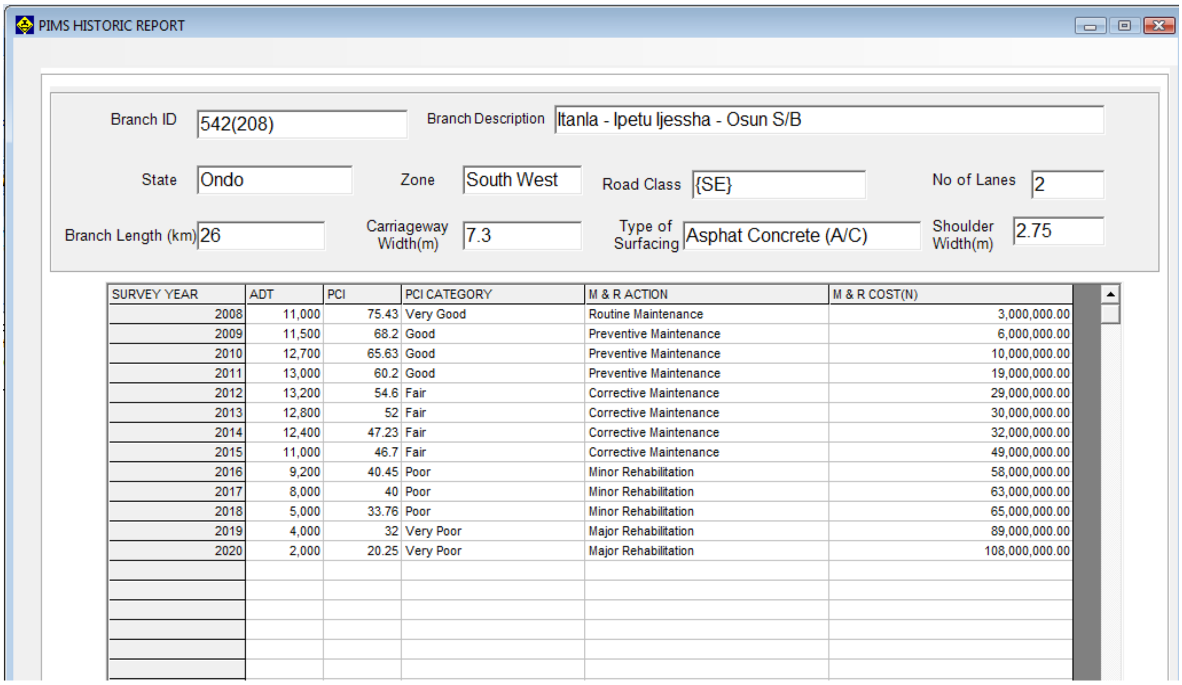
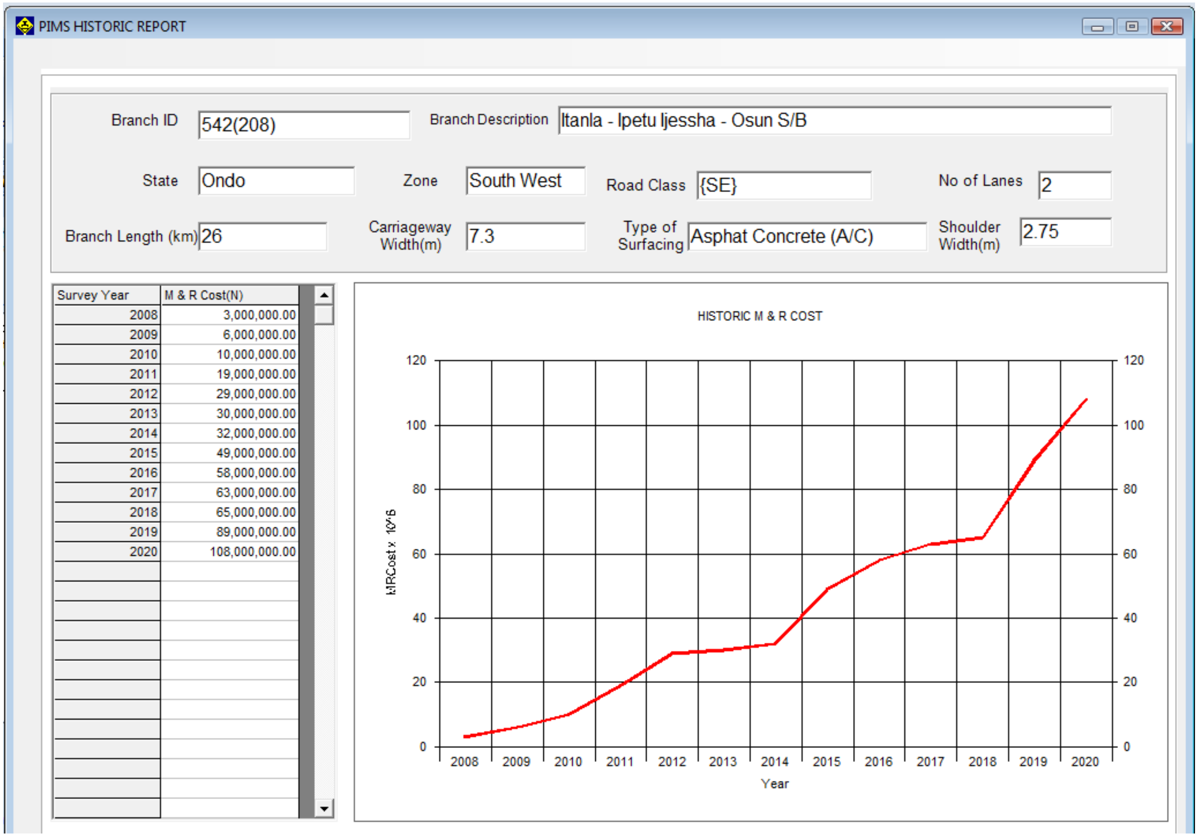


Figure 4.13: Historic PCI Report Display for a Selected Road and Range of Years



SURVEY YEAR	ADT	PCI	PCI CATEGORY	M & R ACTION	M & R COST(N)
2008	11,000	75.43	Very Good	Routine Maintenance	3,000,000.00
2009	11,500	68.2	Good	Preventive Maintenance	6,000,000.00
2010	12,700	65.63	Good	Preventive Maintenance	10,000,000.00
2011	13,000	60.2	Good	Preventive Maintenance	19,000,000.00
2012	13,200	54.6	Fair	Corrective Maintenance	29,000,000.00
2013	12,800	52	Fair	Corrective Maintenance	30,000,000.00
2014	12,400	47.23	Fair	Corrective Maintenance	32,000,000.00
2015	11,000	46.7	Fair	Corrective Maintenance	49,000,000.00
2016	9,200	40.45	Poor	Minor Rehabilitation	58,000,000.00
2017	8,000	40	Poor	Minor Rehabilitation	63,000,000.00
2018	5,000	33.76	Poor	Minor Rehabilitation	65,000,000.00
2019	4,000	32	Very Poor	Major Rehabilitation	89,000,000.00
2020	2,000	20.25	Very Poor	Major Rehabilitation	108,000,000.00

Figure 4.14: Combined Historic Report Display for a Selected Road and Range of Years



Survey Year	M & R Cost(N)
2008	3,000,000.00
2009	6,000,000.00
2010	10,000,000.00
2011	19,000,000.00
2012	29,000,000.00
2013	30,000,000.00
2014	32,000,000.00
2015	49,000,000.00
2016	58,000,000.00
2017	63,000,000.00
2018	65,000,000.00
2019	89,000,000.00
2020	108,000,000.00

Figure 4.15: Historic M&R Costs Report Display for a Selected Road and Range of Years

Graphs, such as this, can be used to observe the trend of the traffic or pavement condition and provides very useful information to pavement managers with just the touch of a button.

4.4 GENERATING PREDICTED REPORT

The developed PIMS is also configured to predict future ADT (Figure 4.16) for any selected road section for which a current ADT is known (from survey).

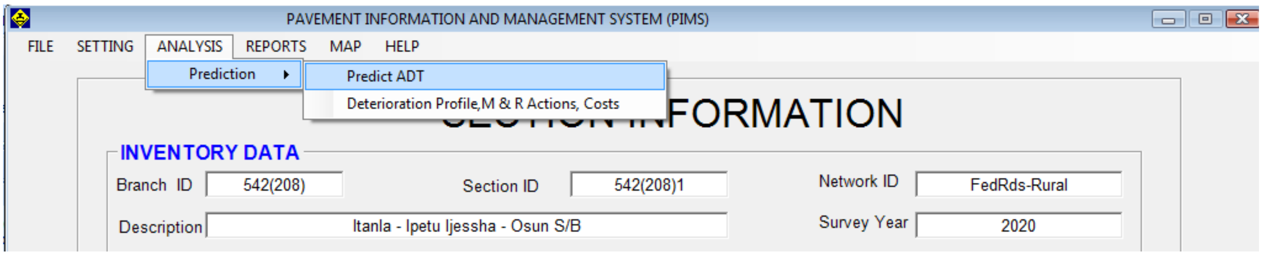


Figure 4.16: Accessing the 'Predict ADT' Menu

The 'PREDICTION DATA' dialogue box (Figure 4.17) allows the input of basic data such as 'Year of Last Survey', 'Year of Construction/Last major Rehabilitation', 'ADT at Year of Survey', 'Year to Predict for' and 'Traffic Growth Rate'. The 'PREDICT' button (lower left corner of the dialogue box) is clicked and the result is displayed. Figure 4.18 displays the result for Itanla – Ipetu Ijesha – Osun S/B road section.

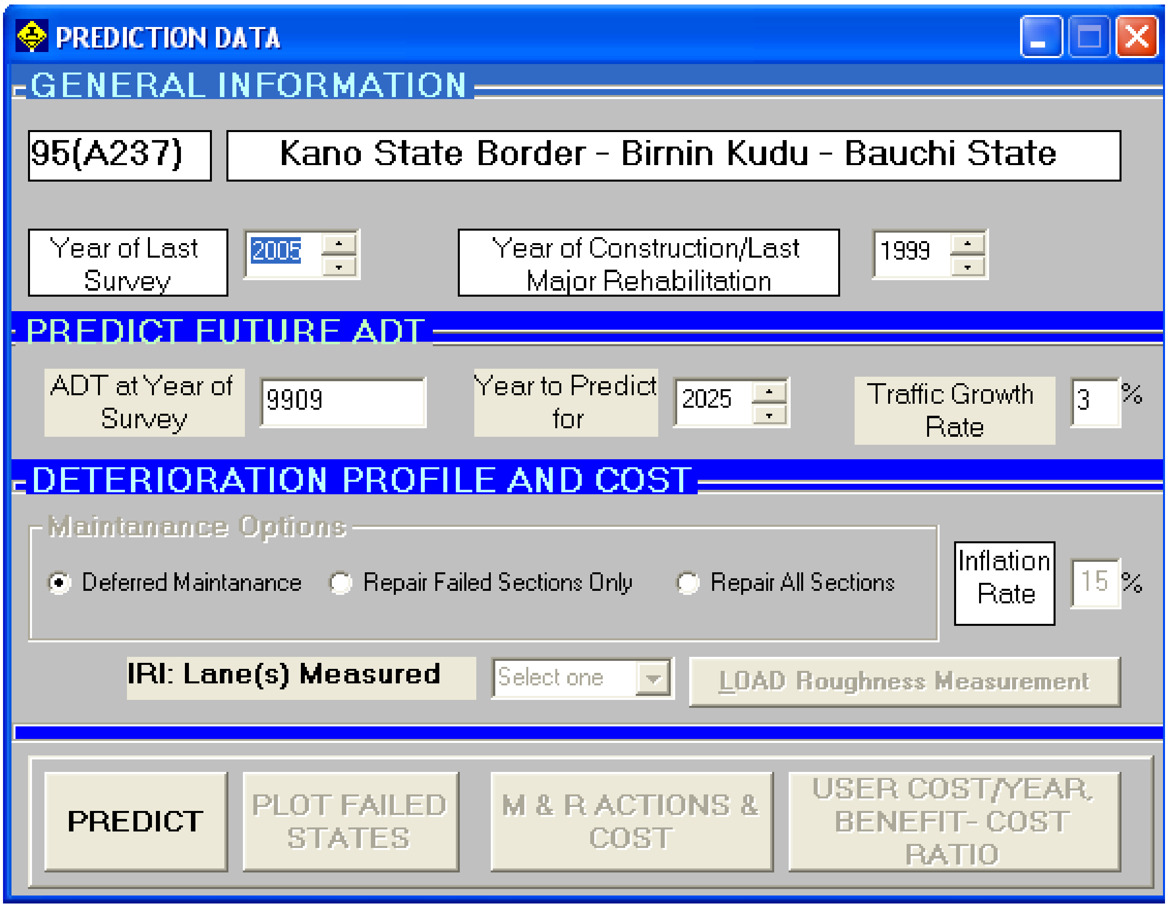


Figure 4.17: 'PREDICTION DATA' Dialogue Box

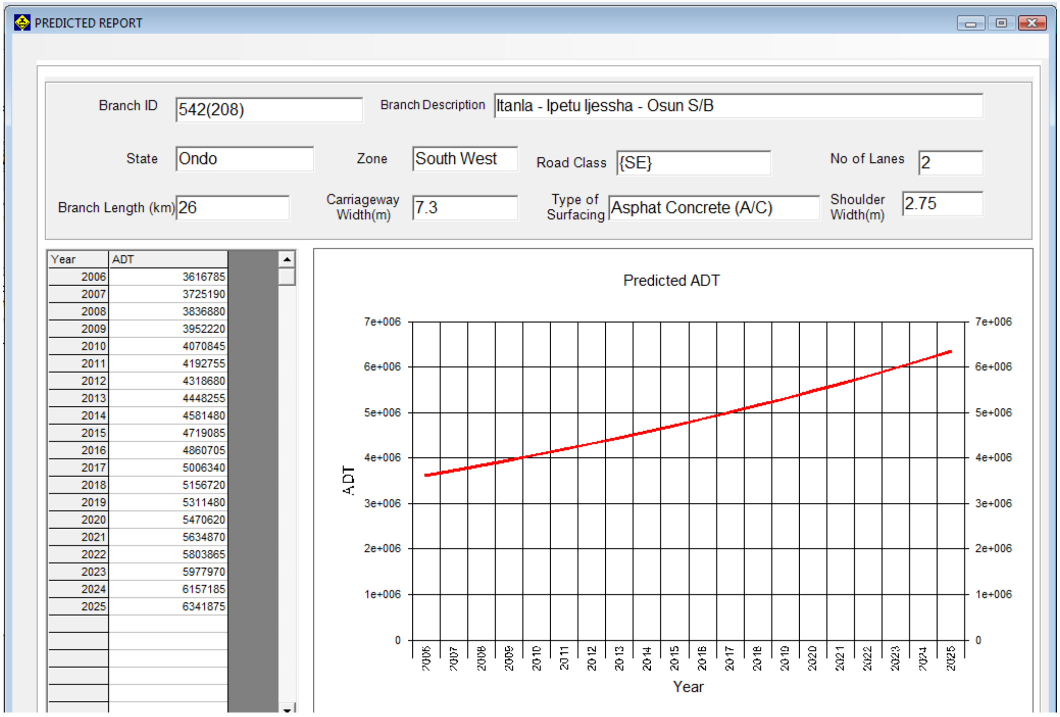


Figure 4.18: Results for Predicted ADT

4.5 THEMATIC MAP DISPLAY OF HISTORIC PCI, M&R ACTIONS AND ADT

The desired parameter (PCI Category, M&R Action or ADT) is selected, followed by the corresponding year for which information is required. The type of chart (pie or bar) is selected and thereafter the 'EXECUTE' button is clicked. If for example the "PCI Category" is selected, the PIMS internally extracts and computes, from the database, the percent values of pavement true areas falling within each PCI rating. The percent results are then automatically displayed for each PCI category and represented as pie / bar chart. The 'Show Map' button is clicked to display the results in thematic map format.

Figures 4.19a and 4.19b show how the PIMS displays the historic condition of the federal rural highways network for a particular selected year (2008). For the parameters used, the highway network map shows those highway sections that have failed (red coloured), in very poor condition (black coloured), in poor condition (magenta coloured), and in fair condition (cyan coloured). Similarly, sections in good condition are shown as (green coloured), in very good condition (blue coloured) and those sections in excellent condition (yellow coloured). Sections with gray colour represent those with unavailable data. The ranges of the PCI used to classify the condition of the pavement sections are also indicated.

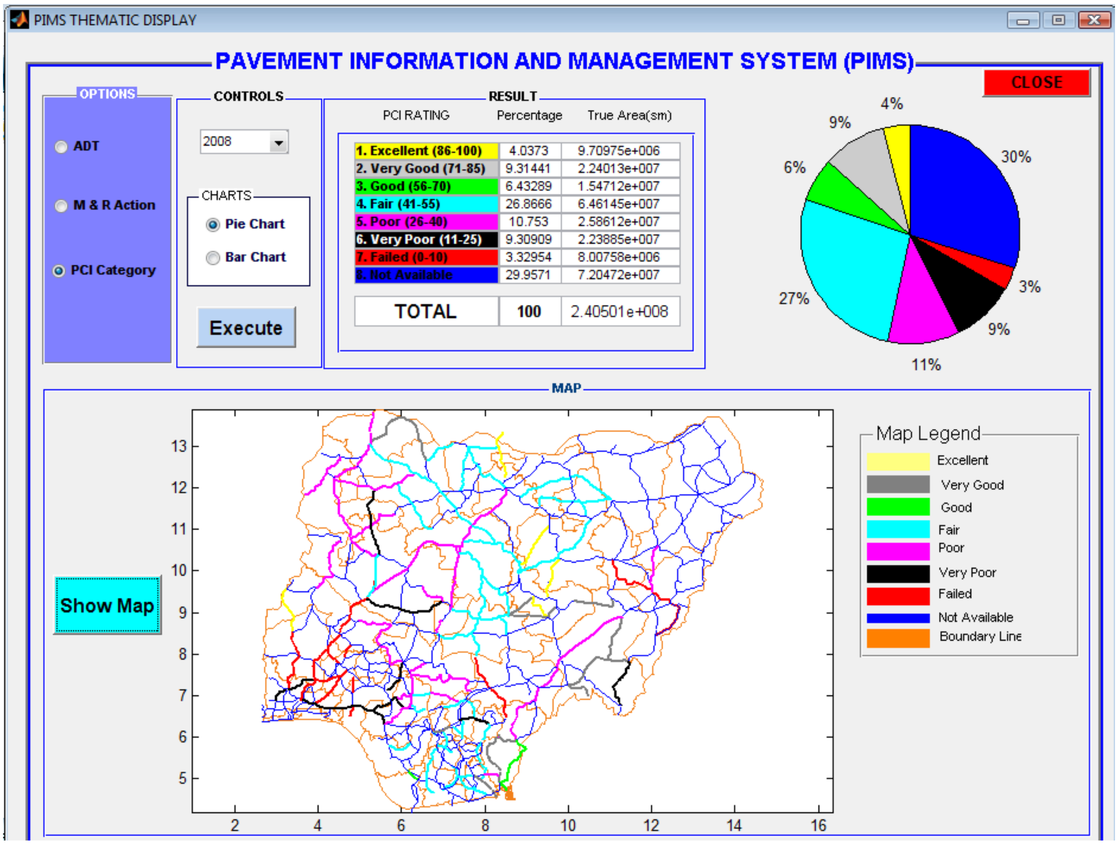


Figure 4.19a: Example of Thematic Map and Pie Chart of Historic PCI

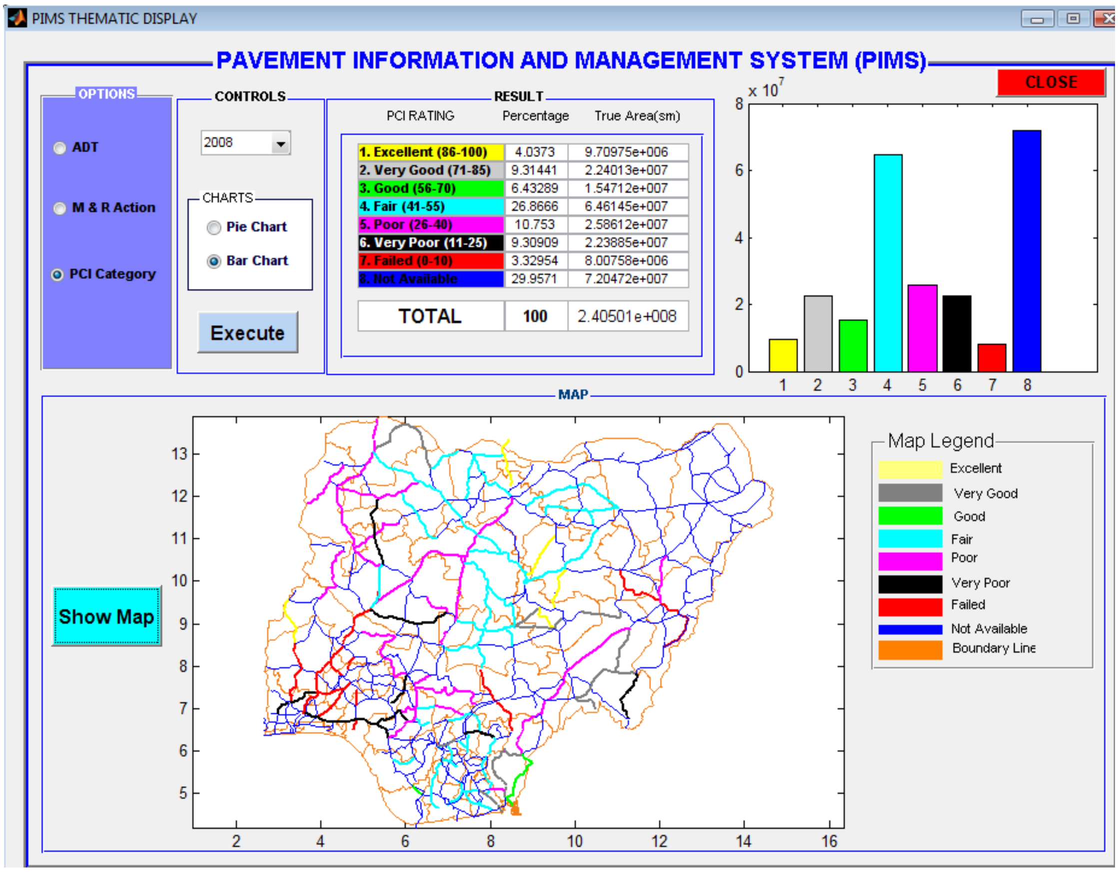


Figure 4.19b: Example of Thematic Map and Bar Chart of Historic PCI

A. THEMATIC MAP OF HISTORIC M&R ACTIONS

Figure 4.20a and 4.20b show an example of the system's ability to display thematic map and charts for historic M&R activities. Having first clicked on the radio button besides the 'M&R ACTION', the user selects the desired year for which information is required and the chart type and then clicks the 'EXECUTE' button. Based on the previously stored information (in the PIMS database), the system calculates percent area for the different M&R activities carried out on various road sections of the federal rural highway network. The results are presented for a particular year (say, 2008), and displayed in different colours. The 'Show Map' button is clicked to display the results in thematic map format.

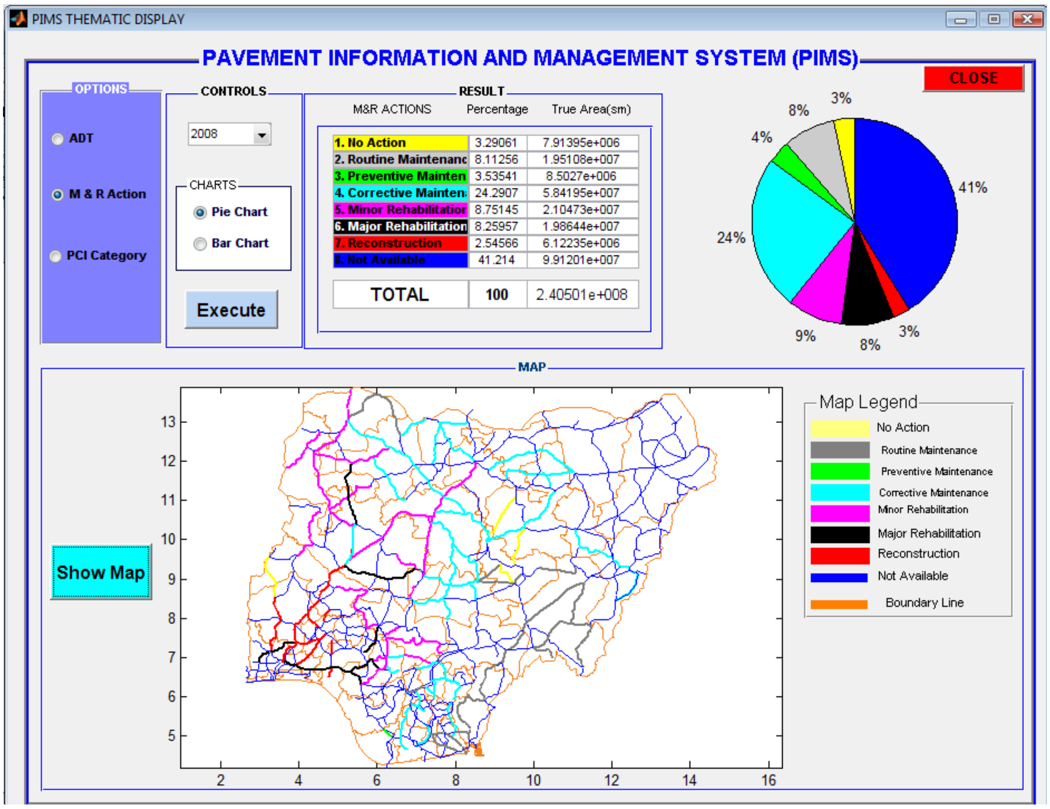


Figure 4.20a: Example of Thematic Map and Pie Chart of Historic M&R Actions

B. THEMATIC MAP OF HISTORIC ADT

In similar manner, historic ADT data for any particular year (for which data is available) can be displayed for the road sections within the federal rural highway network. Different colours of the map show different levels of ADT on the road sections.

The different levels of ADT are shown in a legend and differentiated with colours on the charts and the map (Figures 4.21a and 4.21b).

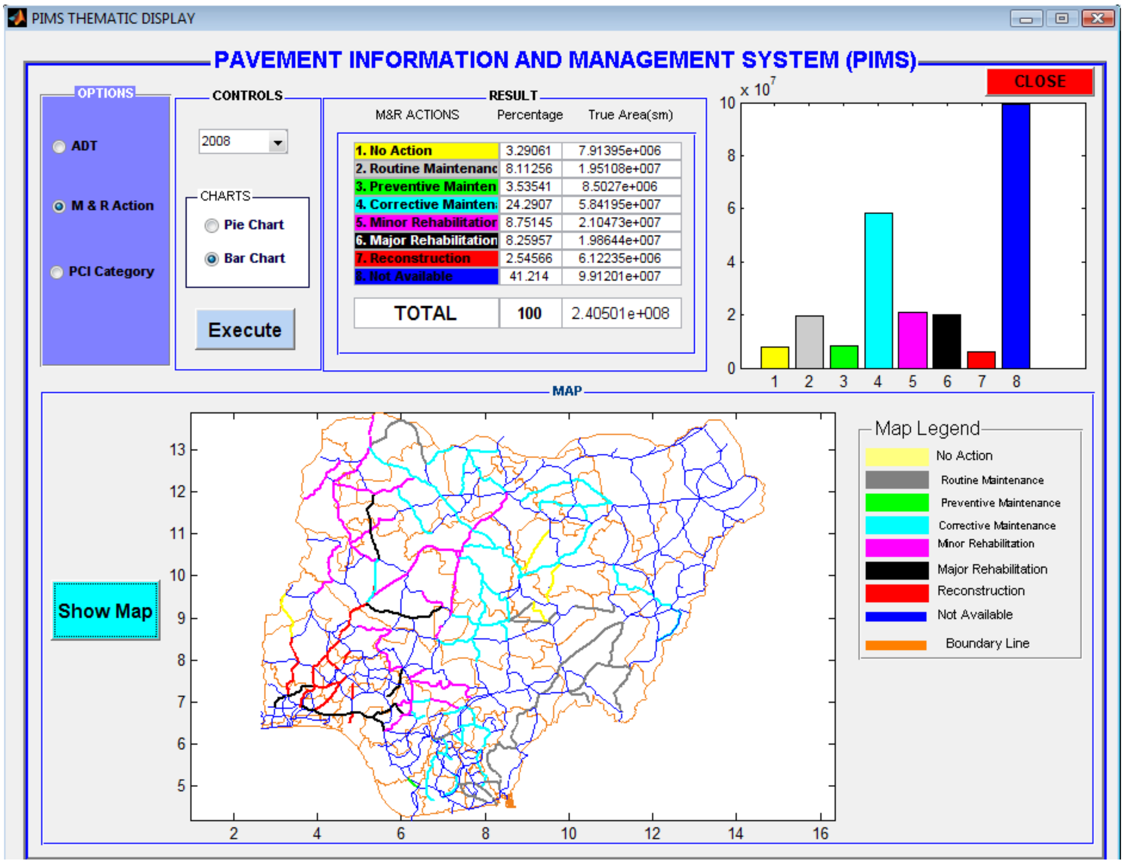


Figure 4.20b: Example of Thematic Map and Bar Chart of Historic M&R Actions

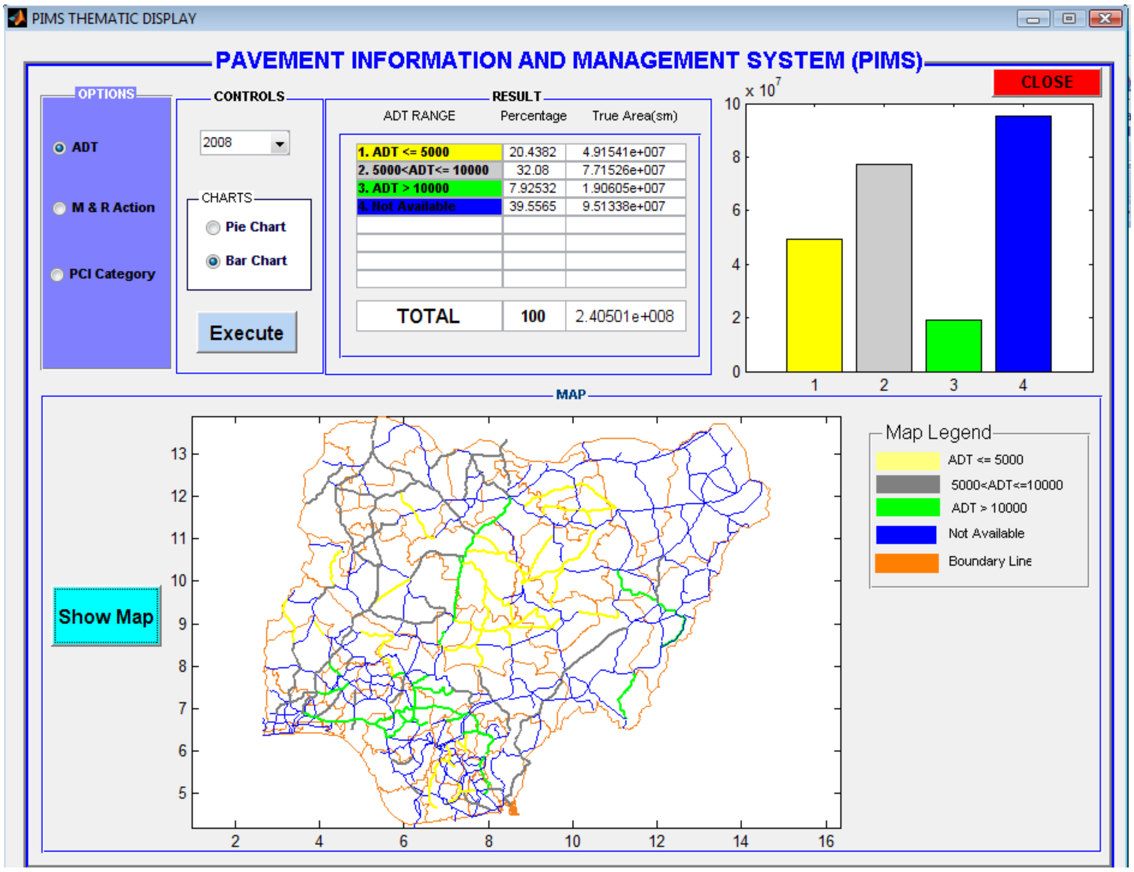


Figure 4.21a: Example of Thematic Map and Bar Chart of Historic ADT

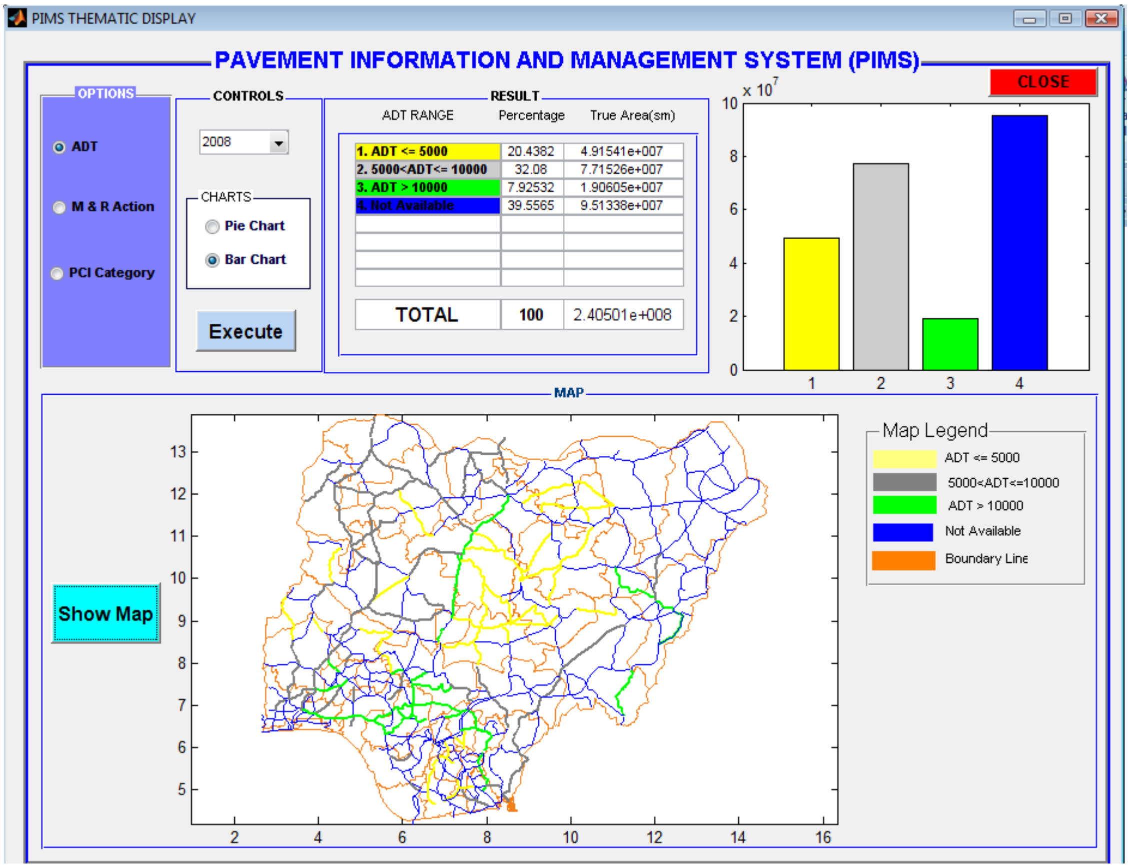


Figure 4.21b: Example of Thematic Map and Bar Chart of Historic ADT

4.6 RESULTS FROM ANALYSES OF MAINTENANCE OPTION 1 (DEFERRED MAINTENANCE)

For each of the three maintenance options adopted, results were obtained for user costs/km, ideal/actual intervention cost and total system cost per km for each year of analysis (year 1 to 20). Results were also obtained for the deterioration profiles under the three maintenance options adopted.

Figure 4.22 depicts the tabular and graphical PIMS display of the deterioration profile for ‘Deferred Maintenance’ option while Tables 4.4 and 4.5 give the extracted deterioration profile and cost computation results, respectively. The full and extracted graphical displays of the deterioration profiles are shown in Figures 4.23a and 4.23b respectively.

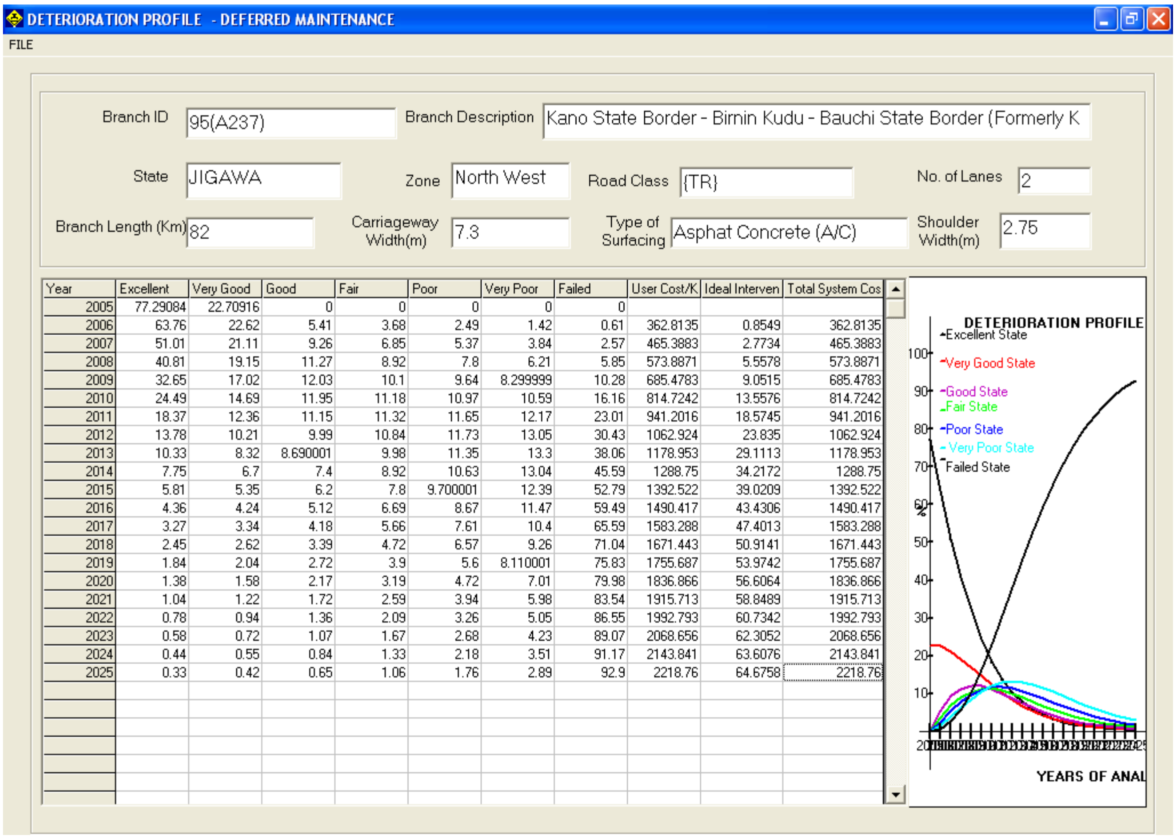


Figure 4.22: Tabular and Graphical PIMS Display of the Deterioration Profile for 'Deferred Maintenance' Option for the Case Study Road

TABLE 4.4: DETERIORATION PROFILE FOR 'DEFERRED MAINTENANCE' OPTION

S/No.	YEAR	PERCENTAGES OF DIFFERENT STATES OF THE ROAD						
		1	2	3	4	5	6	7
0	2005	77.29	22.71	0.00	0.00	0.00	0.00	0.00
1.	2006	63.76	22.62	5.41	3.68	2.49	1.42	0.61
2.	2007	51.01	21.11	9.26	6.85	5.37	3.84	2.57
3.	2008	40.81	19.15	11.27	8.92	7.80	6.21	5.85
4.	2009	32.65	17.02	12.03	10.10	9.64	8.30	10.28
5.	2010	24.49	14.69	11.95	11.18	10.97	10.59	16.16
6.	2011	18.37	12.36	11.15	11.32	11.65	12.17	23.01
7.	2012	13.78	10.21	9.99	10.84	11.73	13.05	30.43
8.	2013	10.33	8.32	8.69	9.98	11.35	13.30	38.06
9.	2014	7.75	6.70	7.40	8.92	10.63	13.04	45.59
10.	2015	5.81	5.35	6.20	7.80	9.70	12.39	52.79
11.	2016	4.36	4.24	5.12	6.69	8.67	11.47	59.49
12.	2017	3.27	3.34	4.18	5.66	7.61	10.40	65.59
13.	2018	2.45	2.62	3.39	4.72	6.57	9.26	71.04
14.	2019	1.84	2.04	2.72	3.90	5.60	8.11	75.83
15.	2020	1.38	1.58	2.17	3.19	4.72	7.01	79.98
16.	2021	1.04	1.22	1.72	2.59	3.94	5.98	83.54
17.	2022	0.78	0.94	1.36	2.09	3.26	5.05	86.55
18.	2023	0.58	0.72	1.07	1.67	2.68	4.23	89.07
19.	2024	0.44	0.55	0.84	1.33	2.18	3.51	91.17
20.	2025	0.33	0.42	0.65	1.06	1.76	2.89	92.90

TABLE 4.5: COST COMPUTATIONS FOR 'DEFERRED MAINTENANCE' OPTION

YEAR	USER COST/KM N=x 10^6	IDEAL INTERVENTION COST (Nx 10^6)	TOTAL SYSTEM COST (Nx10^6)
2005			
2006	362.8218	0.8549	362.8218
2007	465.3963	2.7734	465.3963
2008	573.8952	5.5578	573.8952
2009	685.4869	9.0515	685.4869
2010	814.7334	13.5576	814.7334
2011	941.2118	18.5745	941.2118
2012	1,062.9360	23.8350	1,062.9360
2013	1,178.9660	29.1113	1,178.9660
2014	1,288.7650	34.2172	1,288.7650
2015	1,392.5390	39.0209	1,392.5390
2016	1,490.4360	43.4306	1,490.4360
2017	1,583.3090	47.4013	1,583.3090
2018	1,671.4670	50.9141	1,671.4670
2019	1,755.7120	53.9742	1,755.7120
2020	1,836.8930	56.6064	1,836.8930
2021	1,915.7420	58.8489	1,915.7420
2022	1,992.8240	60.7342	1,992.8240
2023	2,068.6880	62.3052	2,068.6880
2024	2,143.8750	63.6076	2,143.8750
2025	2,218.7960	64.6758	2,218.7960

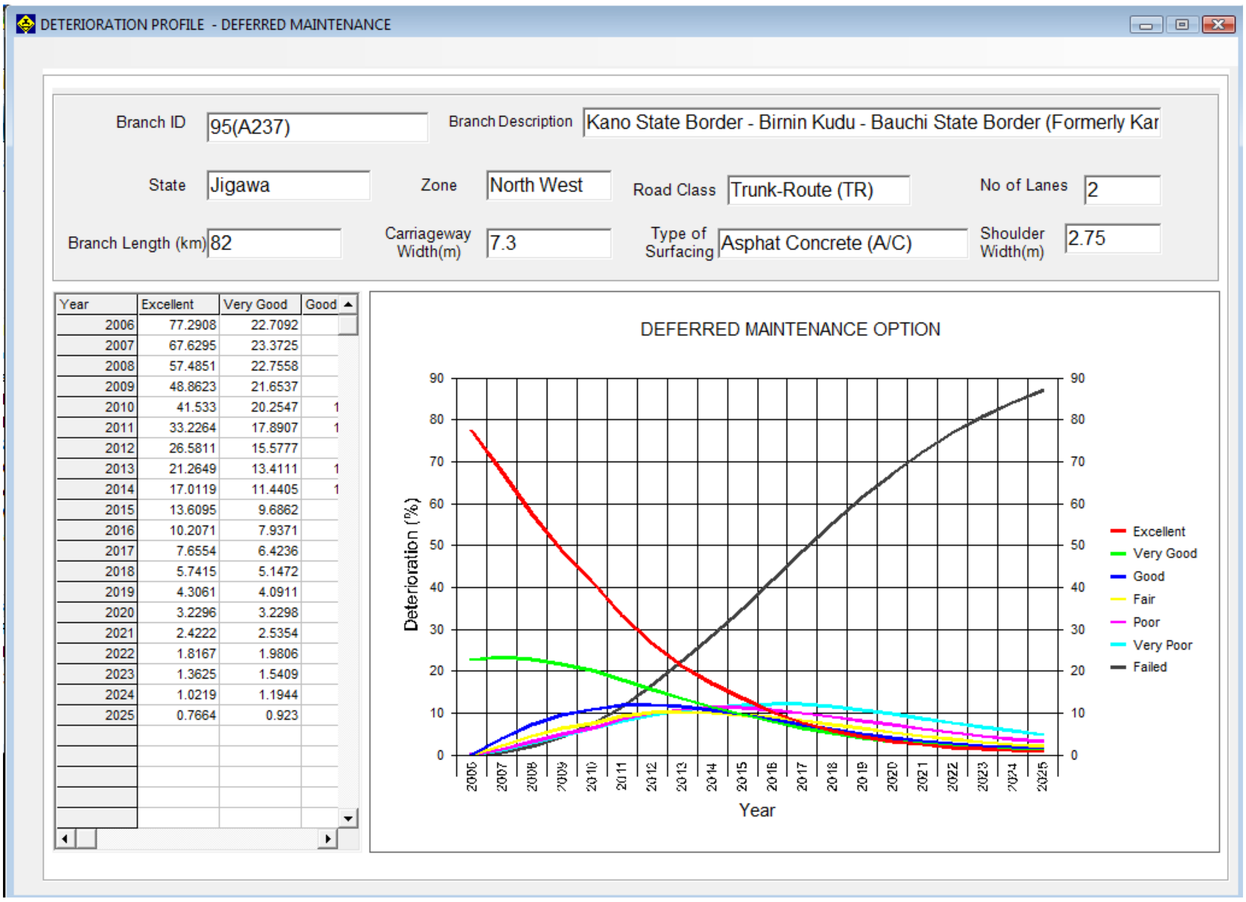


Figure 4.23a: Full Graphical Display of the Deterioration Profile for 'Deferred Maintenance' Option for the Case Study Road

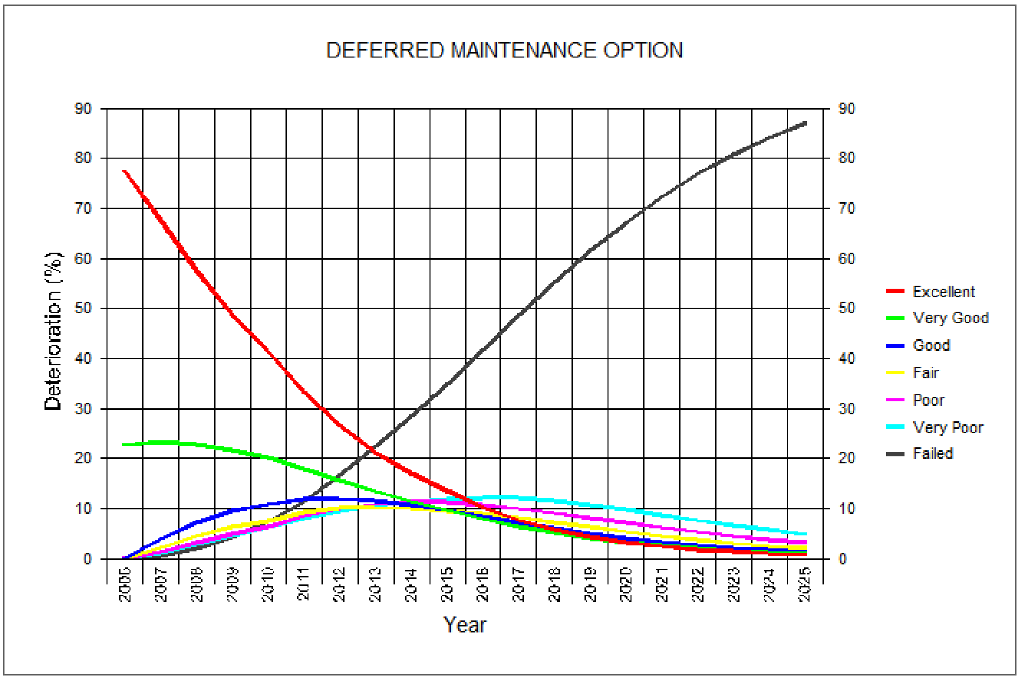
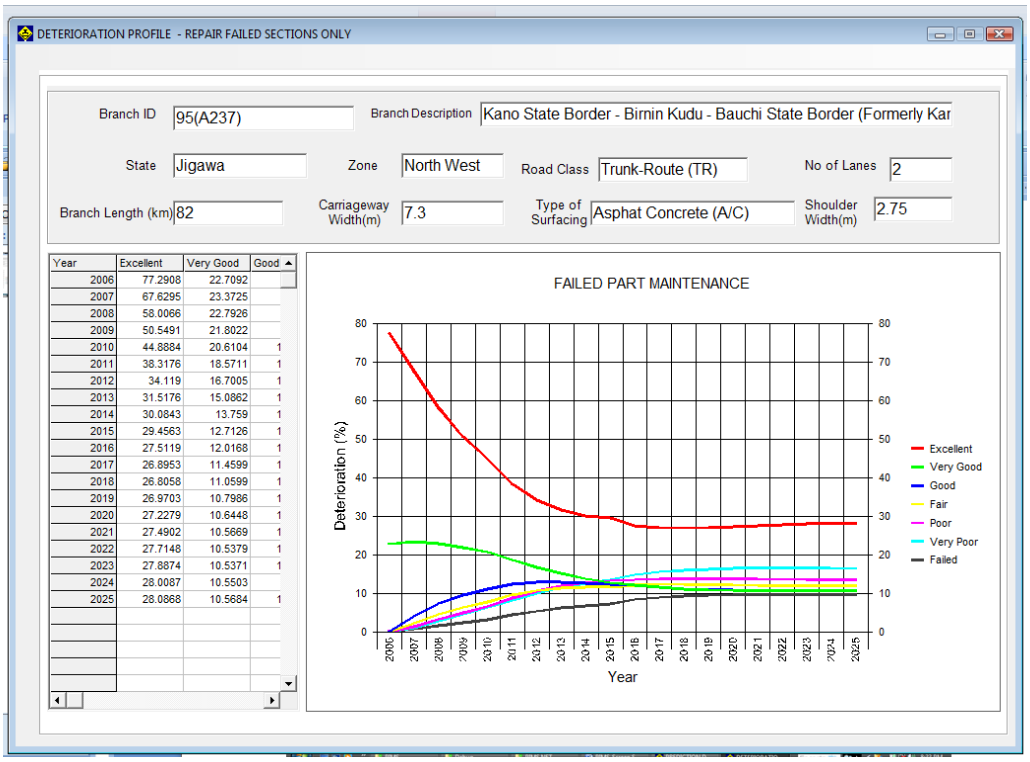


Figure 4.23b: Extracted Full Graphical Display of the Deterioration Profile for 'Deferred Maintenance' Option for the Case Study Road

4.7 RESULTS FROM ANALYSES OF MAINTENANCE OPTION 2 (REPAIR FAILED SECTIONS ONLY)

Figure 4.24 depicts the tabular and graphical PIMS display of the deterioration profile for 'Repair Failed Sections Only' option while Tables 4.6 and 4.7 give the extracted deterioration profile and cost computation results, respectively.



Year	Excellent	Very Good	Good
2006	77.2908	22.7092	
2007	67.6295	23.3725	
2008	58.0066	22.7926	
2009	50.5491	21.8022	
2010	44.8884	20.6104	1
2011	38.3176	18.5711	1
2012	34.119	16.7005	1
2013	31.5176	15.0862	1
2014	30.0843	13.759	1
2015	29.4563	12.7126	1
2016	27.5119	12.0168	1
2017	26.8953	11.4599	1
2018	26.8058	11.0599	1
2019	26.9703	10.7986	1
2020	27.2279	10.6448	1
2021	27.4902	10.5669	1
2022	27.7148	10.5379	1
2023	27.8874	10.5371	1
2024	28.0087	10.5503	
2025	28.0868	10.5684	1

Figure 4.24: Tabular and Graphical PIMS Display of the Deterioration Profile for 'Repair Failed Sections Only' Option for the Case Study Road

TABLE 4.6: DETERIORATION PROFILE FOR MAINTENANCE OPTION 2 (REPAIR FAILED SECTIONS ONLY)

YEAR	PERCENTAGES OF DIFFERENT STATES OF THE ROAD						
	1	2	3	4	5	6	7
2005	77.29	22.71	0.00	0.00	0.00	0.00	0.00
2006	63.77	22.62	5.41	3.68	2.49	1.42	0.61
2007	51.50	21.15	9.29	6.87	5.38	3.85	1.96
2008	42.77	19.34	11.42	9.03	7.87	6.27	3.31
2009	36.86	17.50	12.42	10.39	9.86	8.46	4.51
2010	31.03	15.77	12.79	11.85	11.49	10.99	6.09
2011	27.84	14.19	12.60	12.54	12.61	12.96	7.27
2012	26.33	12.92	12.17	12.75	13.30	14.40	8.15
2013	25.86	11.97	11.70	12.69	13.66	15.37	8.76
2014	25.96	11.32	11.29	12.52	13.79	15.98	9.14
2015	26.32	10.91	10.97	12.32	13.79	16.32	9.37
2016	26.77	10.67	10.75	12.13	13.72	16.48	9.48
2017	27.19	10.55	10.60	11.98	13.63	16.52	9.52
2018	27.53	10.51	10.52	11.87	13.54	16.50	9.52
2019	27.79	10.51	10.48	11.80	13.46	16.46	9.50
2020	27.97	10.53	10.47	11.76	13.40	16.41	9.47
2021	28.08	10.55	10.47	11.74	13.36	16.36	9.44
2022	28.14	10.57	10.48	11.73	13.33	16.32	9.42
2023	28.17	10.59	10.49	11.73	13.32	16.29	9.40
2024	28.18	10.61	10.50	11.74	13.31	16.27	9.39
2025	28.18	10.62	10.51	11.74	13.31	16.26	9.38

TABLE 4.7: COST COMPUTATIONS FOR MAINTENANCE OPTION 2 (REPAIR FAILED SECTIONS ONLY)

YEAR	USER COST/KM ₦X 10^6	ACTUAL INTERVENTION COST/KM ₦X 10^6	TOTAL SYSTEM COST/KM ₦X10^6
2005			
2006	362.8218	0.4209	363.2427
2007	459.4332	1.3524	460.7856
2008	549.0830	2.2839	551.3669
2009	628.5058	3.1119	631.6177
2010	716.2820	4.2021	720.4841
2011	787.3592	5.0163	792.3755
2012	844.8798	5.6235	850.5033
2013	891.1698	6.0444	897.2142
2014	929.2892	6.3066	935.5958
2015	962.2647	6.4653	968.7300
2016	992.0205	6.5412	998.5617
2017	1,020.3460	6.5688	1,026.9150
2018	1,048.6150	6.5688	1,055.1840
2019	1,077.6630	6.5550	1,084.2180
2020	1,107.7770	6.5343	1,114.3120
2021	1,139.0800	6.5136	1,145.5940
2022	1,171.8220	6.4998	1,178.3210
2023	1,206.0670	6.4860	1,212.5520
2024	1,241.7810	6.4791	1,248.2600
2025	1,278.7250	6.4722	1,285.1980

4.8 RESULTS FROM ANALYSES FOR MAINTENANCE OPTION 3 (REPAIR ALL SECTIONS)

Figure 4.25 depicts the tabular and graphical PIMS display of the deterioration profile for 'Repair All Sections' option while Tables 4.8 and 4.9 give the extracted deterioration profile and cost computation results, respectively.

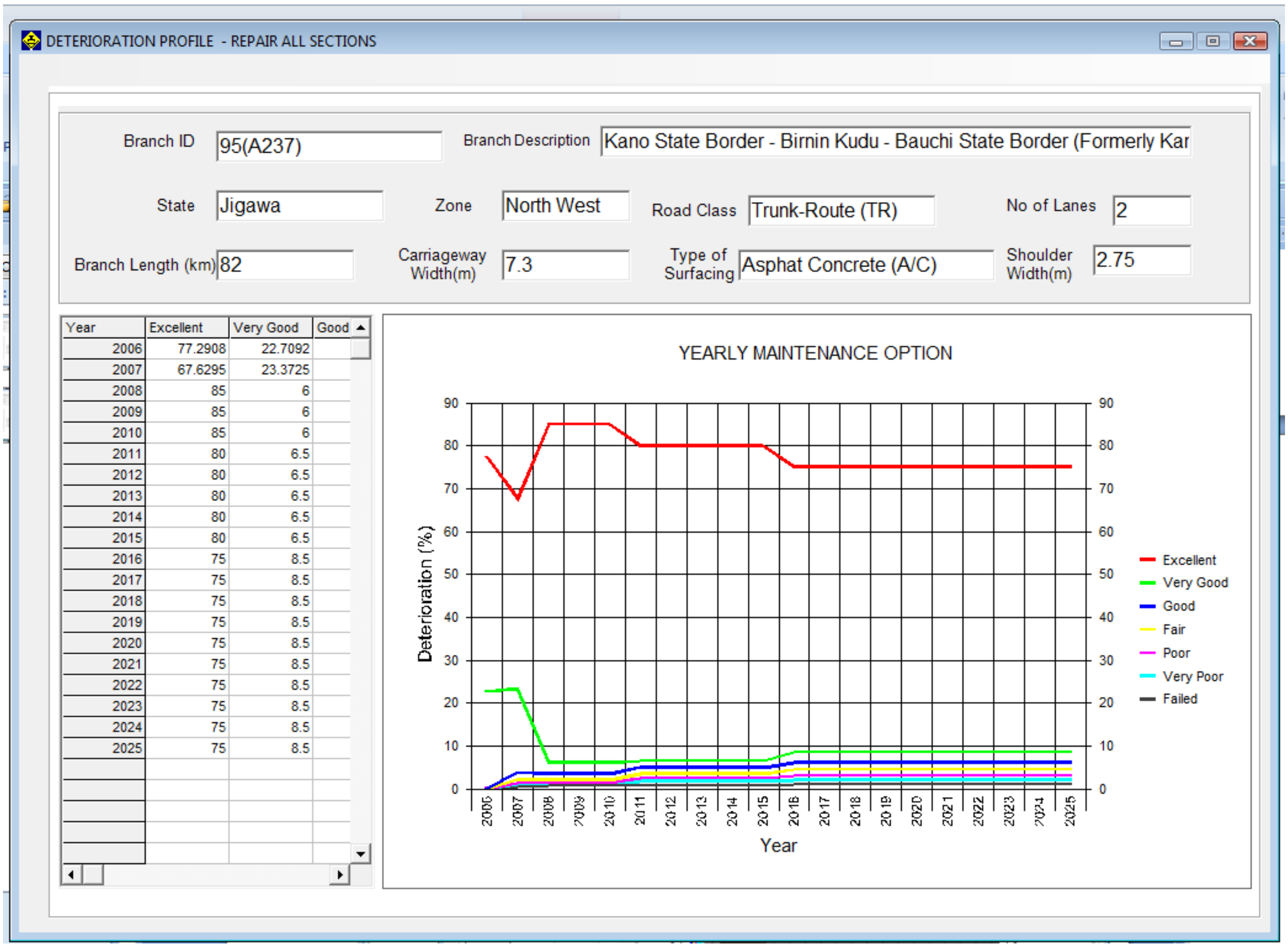


Figure 4.25: Tabular and Graphical PIMS Display of the Deterioration Profile for 'Repair All Sections' Option for the Case Study Road

4.9 COMBINED DETERIORATION PROFILE RESULTS

The effects of the three maintenance options on the deterioration of a road are best captured when superimposed together as shown in Figure 4.26 and Table 4.10. To display the graphs, the user selects the 'Plot Failed States' button from the 'PREDICTION DATA' dialogue box (Figure 4.17).

TABLE 4.8: DETERIORATION PROFILE FOR MAINTENANCE OPTION 3 (REPAIR ALL SECTIONS)

YEAR	PERCENTAGES OF DIFFERENT STATES OF THE ROAD						
	1	2	3	4	5	6	7
2005	77.29	22.71	0.00	0.00	0.00	0.00	0.00
2006	63.76	22.62	5.41	3.68	2.49	1.42	0.61
2007	80.00	6.50	5.00	3.50	2.50	1.75	0.75
2008	80.00	6.50	5.00	3.50	2.50	1.75	0.75
2009	80.00	6.50	5.00	3.50	2.50	1.75	0.75
2010	75.00	8.50	6.00	4.50	3.00	2.00	1.00
2011	75.00	8.50	6.00	4.50	3.00	2.00	1.00
2012	75.00	8.50	6.00	4.50	3.00	2.00	1.00
2013	75.00	8.50	6.00	4.50	3.00	2.00	1.00
2014	75.00	8.50	6.00	4.50	3.00	2.00	1.00
2015	75.00	8.50	6.00	4.50	3.00	2.00	1.00
2016	75.00	8.50	6.00	4.50	3.00	2.00	1.00
2017	75.00	8.50	6.00	4.50	3.00	2.00	1.00
2018	75.00	8.50	6.00	4.50	3.00	2.00	1.00
2019	75.00	8.50	6.00	4.50	3.00	2.00	1.00
2020	75.00	8.50	6.00	4.50	3.00	2.00	1.00
2021	75.00	8.50	6.00	4.50	3.00	2.00	1.00
2022	75.00	8.50	6.00	4.50	3.00	2.00	1.00
2023	75.00	8.50	6.00	4.50	3.00	2.00	1.00
2024	75.00	8.50	6.00	4.50	3.00	2.00	1.00
2025	75.00	8.50	6.00	4.50	3.00	2.00	1.00

TABLE 4.9: COST COMPUTATIONS FOR MAINTENANCE OPTION 3 (REPAIR ALL SECTIONS)

YEAR	USER COST/KM ₦X 10^6	ACTUAL INTERVENTION COST/KM ₦X 10^6	TOTAL SYSTEM COST/KM ₦X10^6
2005			
2006	362.8218	0.8549	363.6767
2007	370.4355	0.9772	371.4127
2008	381.5486	0.9772	382.5258
2009	392.9951	0.9772	393.9723
2010	423.4396	1.2291	424.6687
2011	436.1428	1.2291	437.3719
2012	449.2270	1.2291	450.4561
2013	462.7039	1.2291	463.9330
2014	476.5850	1.2291	477.8141
2015	490.8825	1.2291	492.1116
2016	505.6090	1.2291	506.8381
2017	520.7773	1.2291	522.0064
2018	536.4006	1.2291	537.6297
2019	552.4926	1.2291	553.7217
2020	569.0674	1.2291	570.2965
2021	586.1394	1.2291	587.3685
2022	603.7236	1.2291	604.9527
2023	621.8353	1.2291	623.0645
2024	640.4904	1.2291	641.7195
2025	659.7051	1.2291	660.9342

The plotted deterioration profiles for the three maintenance options considered for the case study road are shown in Figure 4.26 while the values are displayed in Table 4.10.

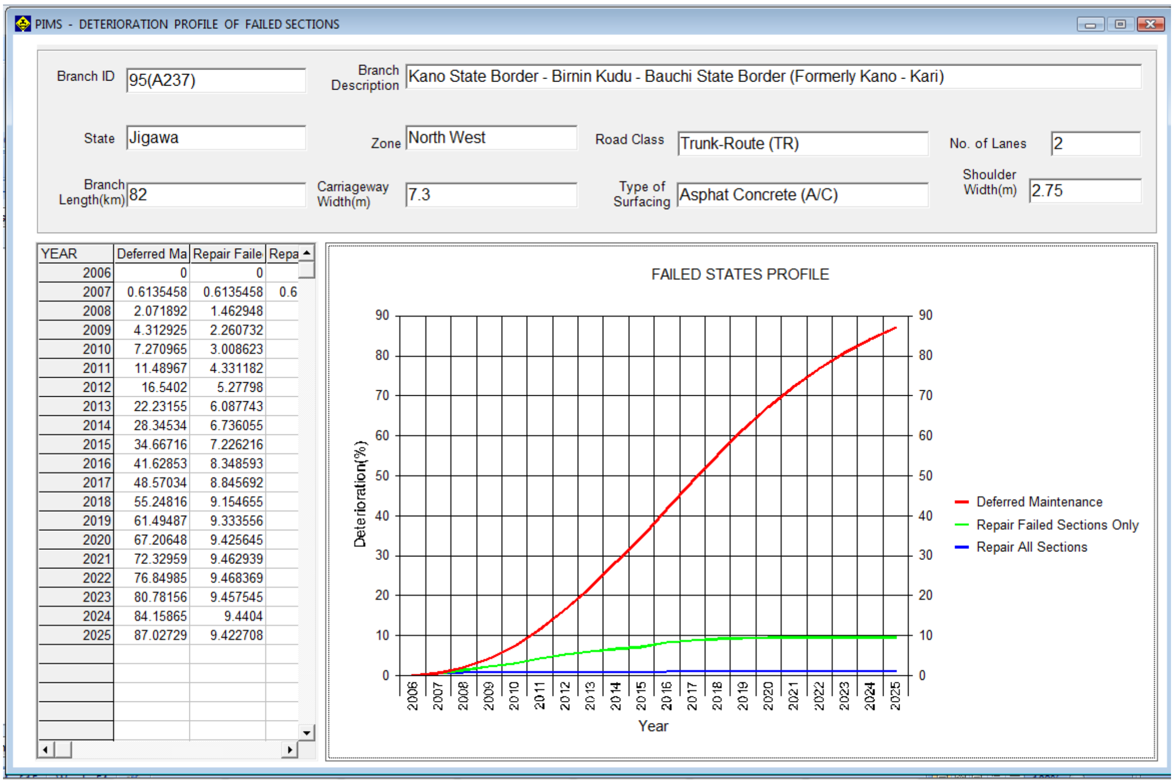


Figure 4.26: Effects of the Three Maintenance Options on Case Study Road Deterioration

TABLE 4.10: DETERIORATION PROFILE DATA FOR ALL THE THREE MAINTENANCE OPTIONS

S/No.	YEAR	DEFERRED MAINTENANCE	REPAIR FAILED SECTIONS ONLY	REPAIR ALL SECTIONS
	2005	0.00	0.00	0.00
1.	2006	0.61	0.61	0.61
2.	2007	2.57	1.96	0.75
3.	2008	5.85	3.31	0.75
4.	2009	10.28	4.51	0.75
5.	2010	16.16	6.09	1.00
6.	2011	23.01	7.27	1.00
7.	2012	30.43	8.15	1.00
8.	2013	38.06	8.76	1.00
9.	2014	45.59	9.14	1.00
10.	2015	52.79	9.37	1.00
11.	2016	59.49	9.48	1.00
12.	2017	65.59	9.52	1.00
13.	2018	71.04	9.52	1.00
14.	2019	75.83	9.50	1.00
15.	2020	79.98	9.47	1.00
16.	2021	83.54	9.44	1.00
17.	2022	86.55	9.42	1.00
18.	2023	89.07	9.40	1.00
19.	2024	91.17	9.39	1.00
20.	2025	92.90	9.38	1.00

4.10 RESULTS FROM BENEFIT-COST ANALYSES

The derived values from the analyses are shown in Tables 4.11 and 4.12. Figure 4.27 displays two results. The first result displays the graphs of the generated user costs for all the three maintenance options for the analysis period of twenty years (2005-2025). The second shows the graphs of benefit/cost plotted against time (period of analyses) for 'Repair All Sections' and 'Repair Failed Sections only'.

Tabular Displays of Predicted Results for M&R Actions and Costs, User Costs and Benefits for Deferred Maintenance Option

The tabulated predicted results for M&R Actions, Costs, User Costs and Benefits based on any of the three maintenance options selected can be easily displayed. From the 'PREDICTION DATA' dialogue box, the user clicks on a radio button against any of the three 'Maintenance Options', selects lane(s) measured for IRI (left, right or both). The 'LOAD Roughness Measurement' tab is clicked to load a previously stored IRI data (see Appendix J for example). Thereafter, the 'M&R Actions & Cost' tab is selected to display the result. Figure 4.28 shows the results for analysis carried out for Deferred Maintenance option.

4.11 DISCUSSION

The deterioration profiles for 'Deferred Maintenance' option show that percentage of the pavement in the failed state increased exponentially from 0 to as high as 92.90 percent in twenty years (Table 4.18).

On the other hand, the percentage of the pavement in excellent condition at year one, reduced drastically from 77.29 to a mere 0.33 at the end of twenty years. Conversely, the accruable user costs/km rose from N362 million after the first year to a stupendous amount of over N2.2 billion by the 20th year (Table 4.19). The graphical displays of the deterioration profile (Figure 4.5a and 4.5b) lend glaring credence to these facts. Interestingly, it would have required the intervention sum of just N362.82 million at year one and N64.67 million at the 20th year to keep the road at an ideal condition state.

The results of the analyses carried out for a situation where only the failed sections are repaired annually are depicted in Figure 4.6, Tables 4.21 and 4.22. Under this maintenance option, the percentage of the pavement in excellent condition (state 1) at year zero reduced significantly from 77.29 to 28.18 while those in failed state (state 7) increased in percentage from 0 to 9.38. The generated user cost/km rose significantly from N362.82 million at year one to N1.27 billion at the end of 20 years. The actual intervention cost/km was N0.42 million at the first year but stabilizes at about N6.0 million from the eighth year.

TABLE 4.11: DERIVED RESULTS FROM BENEFIT/COST ANALYSES FOR CASE STUDY ROAD OPTION 1 – REPAIR FAILED SECTIONS ONLY

S/No	YEAR	DEFERRED MAINTE-NANCE USER COST ₦*10^6 (A)	REPAIR FAILED SECTION ONLY USER COST ₦ *10^6 (B)	ACTUAL INTERVEN-TION COST ₦ *10^6 (C)	BENEFIT ₦ *10^6 (D)=(A-B)	DIS-COUNT FACTOR @ 15% (E)	DIS-COUNTED COST ₦ *10^6 (F) =C*E	DIS-COUNTED BENEFIT ₦ *10^6 (G)=D*E	CUMULA-TIVE COST ₦ *10^6 (H) = $\sum_{i=1}^{n} F_n$	CUMULATIVE BENEFIT ₦ *10^6 (I)= $\sum_{i=1}^{n} G_n$	B/C RATIO (J)= I/H
1.	2006	362.8218	362.8218	0.4209	0.0000	0.8696	0.3660	0.0000	0.3660	0.0000	0.0000
2.	2007	465.3963	459.4332	1.3524	5.9631	0.7561	1.0226	4.5090	1.3886	4.5090	3.2471
3.	2008	573.8952	549.0830	2.2839	24.8122	0.6575	1.5017	16.3144	2.8903	20.8234	7.2046
4.	2009	685.4869	628.5058	3.1119	56.9811	0.5718	1.7792	32.5791	4.6695	53.4025	11.4363
5.	2010	814.7334	716.2820	4.2021	98.4514	0.4972	2.0892	48.9477	6.7587	102.3503	15.1434
6.	2011	941.2118	787.3592	5.0163	153.8526	0.4323	2.1687	66.5147	8.9274	168.8650	18.9153
7.	2012	1,062.9360	844.8798	5.6235	218.0562	0.3759	2.1141	81.9754	11.0415	250.8404	22.7180
8.	2013	1,178.9660	891.1698	6.0444	287.7962	0.3269	1.9759	94.0811	13.0174	344.9215	26.4969
9.	2014	1,288.7650	929.2892	6.3066	359.4758	0.2843	1.7927	102.1855	14.8102	447.1069	30.1892
10.	2015	1,392.5390	962.2647	6.4653	430.2743	0.2472	1.5981	106.3572	16.4083	553.4642	33.7308
11.	2016	1,490.4360	992.0205	6.5412	498.4155	0.2149	1.4060	107.1310	17.8143	660.5952	37.0824
12.	2017	1,583.3090	1,020.3460	6.5688	562.9630	0.1869	1.2278	105.2218	19.0420	765.8170	40.2172
13.	2018	1,671.4670	1,048.6150	6.5688	622.8520	0.1625	1.0676	101.2309	20.1096	867.0479	43.1160
14.	2019	1,755.7120	1,077.6630	6.5550	678.0490	0.1413	0.9264	95.8278	21.0360	962.8756	45.7727
15.	2020	1,836.8930	1,107.7770	6.5343	729.1160	0.1229	0.8030	89.6043	21.8391	1,052.4800	48.1925
16.	2021	1,915.7420	1,139.0800	6.5136	776.6620	0.1069	0.6961	82.9978	22.5351	1,135.4778	50.3870
17.	2022	1,992.8240	1,171.8220	6.4998	821.0020	0.0929	0.6040	76.2923	23.1391	1,211.7701	52.3688
18.	2023	2,068.6880	1,206.0670	6.4860	862.6210	0.0808	0.5241	69.7042	23.6633	1,281.4743	54.1546
19.	2024	2,143.8750	1,241.7810	6.4791	902.0940	0.0703	0.4553	63.3859	24.1185	1,344.8602	55.7605
20.	2025	2,218.7960	1,278.7250	6.4722	940.0710	0.0611	0.3955	57.4386	24.5140	1,402.2988	57.2041

TABLE 4.12: DERIVED RESULTS FROM BENEFIT/COST ANALYSES FOR CASE STUDY ROAD

OPTION 2– REPAIR ALL SECTIONS

S/No	YEAR	DEFERRED MAINTE-NANCE USER COST ₦*10^6 (A)	REPAIR ALL SECTION USERCOST ₦ *10^6 (B)	ACTUAL INTERVEN-TION COST ₦ *10^6 (C)	BENEFIT ₦ *10^6 (D)=(A-B)	DISCOUNT FACTOR @ 15% (E)	DISCOUNTE D COST ₦ *10^6 (F) =C*E	DIS-COUNTED BENEFIT ₦ *10^6 (G)=D*E	CUMULA-TIVE COST ₦ *10^6 (H) = $\sum_{i=1}^{n} F_n$	CUMULATIVE BENEFIT ₦ *10^6 (I)= $\sum_{i=1}^{n} G_n$	B/C RATIO (J)= I/H
1.	2006	362.8218	362.8218	0.8549	0.0000	0.8696	0.7434	0.0000	0.7434	0.0000	0.0000
2.	2007	465.3963	370.4355	0.9772	94.9608	0.7561	0.7389	71.8040	1.4823	71.8040	48.4411
3.	2008	573.8952	381.5486	0.9772	192.3466	0.6575	0.6425	126.4710	2.1248	198.2750	93.3138
4.	2009	685.4869	392.9951	0.9772	292.4918	0.5718	0.5587	167.2331	2.6835	365.5082	136.2039
5.	2010	814.7334	423.4396	1.2291	391.2938	0.4972	0.6111	194.5422	3.2946	560.0503	169.9895
6.	2011	941.2118	436.1428	1.2291	505.0690	0.4323	0.5314	218.3553	3.8260	778.4056	203.4520
7.	2012	1,062.9360	449.2270	1.2291	613.7090	0.3759	0.4621	230.7159	4.2881	1,009.1215	235.3332
8.	2013	1,178.9660	462.7039	1.2291	716.2621	0.3269	0.4018	234.1474	4.6898	1,243.2689	265.0978
9.	2014	1,288.7650	476.5850	1.2291	812.1800	0.2843	0.3494	230.8722	5.0392	1,474.1411	292.5326
10.	2015	1,392.5390	490.8825	1.2291	901.6565	0.2472	0.3038	222.8757	5.3431	1,697.0168	317.6119
11.	2016	1,490.4360	505.6090	1.2291	984.8270	0.2149	0.2642	211.6819	5.6072	1,908.6987	340.3991
12.	2017	1,583.3090	520.7773	1.2291	1,062.5317	0.1869	0.2297	198.5948	5.8370	2,107.2935	361.0255
13.	2018	1,671.4670	536.4006	1.2291	1,135.0664	0.1625	0.1998	184.4800	6.0367	2,291.7735	379.6383
14.	2019	1,755.7120	552.4926	1.2291	1,203.2194	0.1413	0.1737	170.0494	6.2104	2,461.8229	396.4010
15.	2020	1,836.8930	569.0674	1.2291	1,267.8256	0.1229	0.1510	155.8088	6.3615	2,617.6317	411.4812
16.	2021	1,915.7420	586.1394	1.2291	1,329.6026	0.1069	0.1313	142.0877	6.4928	2,759.7194	425.0409
17.	2022	1,992.8240	603.7236	1.2291	1,389.1004	0.0929	0.1142	129.0834	6.6070	2,888.8027	437.2304
18.	2023	2,068.6880	621.8353	1.2291	1,446.8527	0.0808	0.0993	116.9131	6.7064	3,005.7158	448.1885
19.	2024	2,143.8750	640.4904	1.2291	1,503.3846	0.0703	0.0864	105.6358	6.7927	3,111.3516	458.0415
20.	2025	2,218.7960	659.7051	1.2291	1,559.0909	0.0611	0.0751	95.2609	6.8678	3,206.6125	466.9035

PIMS - COST ANALYSIS

(1) - REPAIR FAILED SECTIONS ONLY OPTION

(2) - REPAIR ALL SECTIONS OPTION

Kano State Border - Birnin Kudu - Bauchi State Border (Formerly Kano - Kari) Road

YEAR	COST(1)*10^	BENEFIT(1)*1	C/B RATIO(1	CO
2007	.3681	.	0	
2008	1.1313	4.6969	4.15	
2009	2.157	18.6828	8.66	
2010	3.344	44.3173	13.25	
2011	4.8298	81.3684	16.85	
2012	6.4042	132.2112	20.64	
2013	7.9833	195.9934	24.55	
2014	9.5028	270.8316	28.5	
2015	10.9201	354.2103	32.44	
2016	12.344	441.4401	35.76	
2017	13.6559	532.0109	38.96	
2018	14.8366	623.7356	42.04	
2019	15.8833	714.5515	44.99	
2020	16.8024	802.7403	47.78	
2021	17.6049	887.0015	50.38	
2022	18.303	966.4442	52.8	
2023	18.9094	1,040.536	55.03	
2024	19.4358	1,109.038	57.06	
2025	19.8926	1,171.931	58.91	

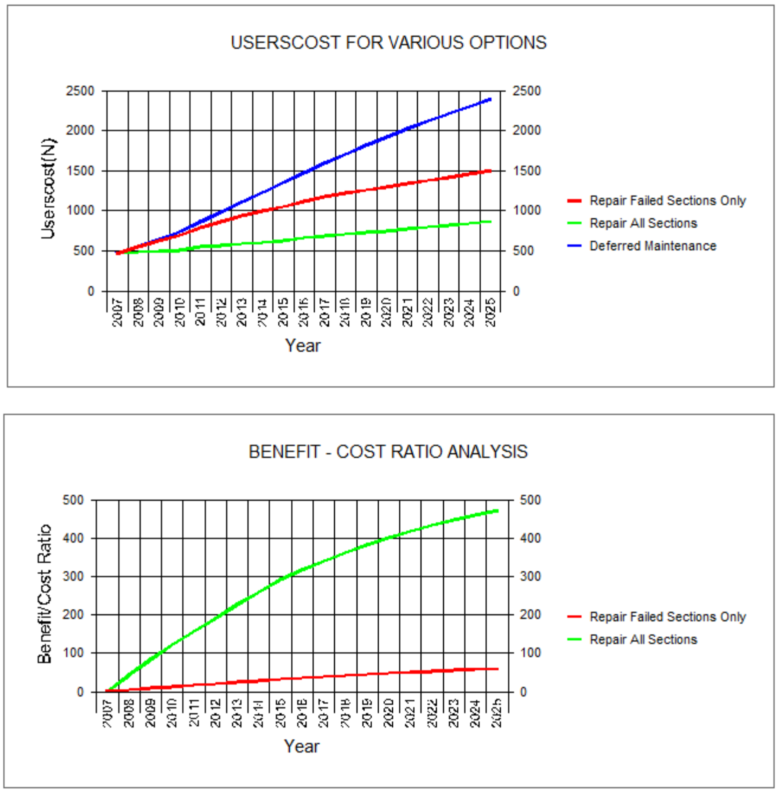


Figure 4.27: Graphs of User Costs and Benefit/Cost against Time (Years of Analysis)

M & R ACTIONS AND COST

M & R ACTIONS AND COST FOR DEFERRED MAINTAINANCE

PRINT

Ikot Ekpene - Itu Road (Parallel Road

YEAR	STATE	LENGTH	M & R ACTIONS	M & R COSTS	USER COSTS	BENEFITS
	Very Poor	5.96	Major Rehabilitation	6.556E+07		
	Failed	27.15	Reconstruction	5.43E+08		
	TOTAL	45		6.8674E+08	460339599.61	-226400368.39
	Exellent	0	No Action	0		
	Very Good	0.11	Routine Maintenance	275000		
	Good	2.35	Preventive Maintenance	9400000		
	Fair	2.74	Corrective Maintenance	1.644E+07		
2017	Poor	4.6	Minor Rehabilitation	3.91E+07		
	Very Poor	5.35	Major Rehabilitation	5.885E+07		
	Failed	29.85	Reconstruction	5.97E+08		
	TOTAL	45		7.21065E+08	478582702.64	-242482321.36
	Exellent	0	No Action	0		
	Very Good	0.08	Routine Maintenance	200000		
	Good	1.71	Preventive Maintenance	6840000		
	Fair	2.18	Corrective Maintenance	1.308E+07		
2018	Poor	3.76	Minor Rehabilitation	3.196E+07		
	Very Poor	4.78	Major Rehabilitation	5.258E+07		
	Failed	32.49	Reconstruction	6.498001E+08		
	TOTAL	45		7.544601E+08	497292694.09	-257167401.91
	Exellent	0	No Action	0		
	Very Good	0.05	Routine Maintenance	125000		
	Good	1.25	Preventive Maintenance	5000000		
	Fair	1.72	Corrective Maintenance	1.032E+07		
2019	Poor	3.04	Minor Rehabilitation	2.584E+07		
	Very Poor	4.14	Major Rehabilitation	4.554E+07		

Figure 4.28: Tabular Displays of Predicted Results for M&R Actions and Costs, User Costs and Benefits for Deferred Maintenance Option

For the option where all the sections of the pavement are brought to the best state annually, the percentage of the portion initially at best condition state increases slightly from 77.29 to 80.0 and thereafter becomes stable at 75 percent from the fifth year (Table 4.22). The portion in the failed state also rose marginally from zero to 0.75 percent at the fifth year and thereafter stabilizes at 1.0 percent. The actual intervention cost/km required to achieve this feat is just N0.85 million by the first year and stabilizes at N1.22 million annually from the fifth year, while the user cost/km increased from N362.82 million at year one and stood at only N659.70 million at the end of the 20th year of analysis (Table 4.23).

In order to best capture the effects of the three maintenance options on the deterioration of the case study road, the percentage results for pavement portion in the failed state were captured and shown in Table 4.24. The graphical displays of the effects are shown in Figure 4.8.

The accruable benefits arising from timely injection of intervention repair funds are vividly shown in the benefit-cost ratio analyses for the ‘Repair All Sections’ and ‘Repair Failed Sections Only’. For the ‘Repair Failed Sections Only’ option (Table 4.25), the cumulative benefit stood at N1.40 billion with a benefit-cost ration of 57.2. On the other hand, the cumulative benefit for the ‘Repair All Sections’ came to over N3.2 billion with a benefit-cost ratio of 466.9.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 GENERAL SUMMARY

The work presented here is an attempt to develop a pavement information and management system (PIMS) that is capable of storing and analysing all pertinent information relating to all the roads within a network. The PIMS is also designed with the ability to integrate data from a variety of sources and provide summarized, strategic information in an easily understandable format for highway managers and decision makers.

To achieve these aims, a computerized condition rating system and M&R procedure was developed and validated. The rating system adopted was the world-renown pavement condition index (PCI) method. The developed PIMS has also been proved to be capable of estimating present and predicted performance of any selected highway section within the network for which survey data are available. User costs and intervention costs models were also incorporated into the system. These have the abilities to predict user costs and ideal/actual intervention costs required for any range of years for any particular road based on the roughness data, initial traffic volume, inflation rate, etc.

In order to make the developed PIMS much more effective and attractive, graphical display of analyzed result in the form of charts and thematic maps were incorporated. A digitized map of the federal roads was generated within ArcView environment. The map is however displayed within Visual Basic environment. The extensive analyses and computations are carried out within the Matlab® environment while the system relied on Visual Basic for the display of the results. With this arrangement, the system is able to display trend of past and present activities and provide information in the form of thematic maps, charts and graphs.

A. PCI-BASED VISUAL PAVEMENT EVALUATION

It has been clearly demonstrated that the developed PIMS fulfils the objective of developing a system with the ability for easy storage and retrieval of relevant pavement information such as information on inventory data, pavement materials and maintenance history.

In order to validate the reliability of the developed automated PCI-based visual pavement evaluation, twelve road sections were selected and visually surveyed. The detailed manual and automated PCI results for the surveyed Jebba-Mokwa-Kotangora (Section I) road are displayed in Table 3.4. Comparison of the two sets of results shows that the developed PIMS can reliably generate PCI results for surveyed roads. This fact is also attested to by the comparison of the section PCI results for the other eleven road sections that were surveyed. The pictures and video recording of distresses as captured on site are easily loaded into the system and displayed.

The developed PIMS is also capable of generating series of condition reports under different categories. The federal roads maintenance agency can use available information to observe the different locations and types of pavement M&R actions performed in a year. Plotted graphs of historic as well as projected ADT data for a selected section of highway network can be used to verify the correct use of traffic growth rate, observe the trend and level of traffic for a particular section of the highway. The M&R Cost option can be selected to display the historic distribution of rehabilitation costs on pavements within the network. The predicted costs of M&R activities required to bring network pavements to a minimum acceptable level of service can also be displayed.

B. PAVEMENT PERFORMANCE AND USER COSTS PREDICTION

This work has been able to demonstrate the effects of different types of maintenance options on pavement in terms of deterioration and accruable user costs. Portions of the case study pavement (in the failed state) after year one of analysis rose from zero percent to a staggering 92.9 percent at the end of twenty years, resulting in a corresponding user cost/km of over N2.2 billion. A paltry ideal intervention cost/km of N0.85 million would have been required at the first year and only N64.67 million required at the 20th year. When only the failed portions of the same road are annually upgraded to the excellent condition, the rate of deterioration increased from zero percent to a moderate 9.38 percent. The corresponding user costs/km increased from N362.82 million to over N1.27 billion requiring an annual actual expenditure /km of around N6.0 million.

However, the biggest gain to both road users and pavement maintenance agency occurs when all sections of the pavement are upgraded to the best state. Under this condition, the percentage of failed state is kept at a very insignificant level – 1.0%. The percentage rise of the accruable user cost/km, from N362.82 million to just over N650 million is due largely to the effect of inflation introduced.

The benefit-cost ratio (B/C) analyses gave an impressive B/C ratio of 466.9 when all sections of the road are constantly upgraded to the best state compared with a B/C ratio of only 57.2 when only the failed portions of the road are constantly repaired. Clearly, this shows that expenditure on regular road maintenance and rehabilitation have high rate of return.

5.2 CONCLUSIONS

From the foregoing detailed work, the following conclusions are reached, viz:

1. For developing countries that obviously cannot successfully utilize many of the sophisticated commercial software available in the market, a simpler but equally effective computerized PIMS has been developed.
2. The constructed performance prediction models are capable of estimating present and predicted performance of any selected highway section. User costs and intervention costs models, for network-level were also developed. Based on this, timely intervention to maintain pavements at appropriate times, using the developed models, will significantly reduce the overall expenditure for both the users and the government.
3. Interfaces within ArcView, Mathlab® and Visual Basic environments that are capable of displaying trend of past and present activities and providing information in thematic maps, charts and graphs have been successfully developed.
4. If properly utilized, the developed system would be very effective in managing the pavements in the federal road network, at the network level. It would also be very useful in assisting pavement engineers and decision makers in planning, programming and budgeting.

5.3 RECOMMENDATIONS AND FURTHER RESEARCH WORK

The determination of the transition matrices is still a weak area, as it was based on subjective opinions. However, since a simple but computerized PIMS has been developed through this work; it is possible to incorporate pavement deterioration modelling based on historical record of the objective function (performance) variation with age (time). In order to achieve this, regular measurement of the condition rating of some selected pavement sections should be carried out over a period of some years. Based on the generated model curves using historical data, future condition rating could then be predicted more accurately.

Difficulties were encountered in the process of incorporating the roads network map to display within ArcView GIS environment. ArcView GIS is a very powerful tool that could really boost the ability of the developed PIMS to perform in-depth spatial queries and display. However, the skill required to customize the GIS software is still lacking and needs to be encouraged. Further research should be geared towards the incorporation of GIS capabilities with the developed PIMS.

Finally, it would be highly encouraging for our development as a nation if the roads maintenance agencies can begin the implementation of the management of roads network by utilizing this locally developed PIMS programme. There is also the need for the country to start planning to adopt some form of automated road data collection system.

5.4 CONTRIBUTIONS TO KNOWLEDGE AND PRACTICE

1. A computerized condition rating system / M&R procedure applicable to flexible pavement sections have been developed and validated.

2. Performance prediction models, capable of estimating present and predicted performance of any selected highway section, have been adapted.

3. An interface incorporating ArcView and Visual Basic environments which is capable of displaying trends of past and present M&R activities and providing information in thematic maps, charts and graphs was also developed.

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