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**Development of a
Pavement Management System**

Kelvin Wang, David Li,
Kirby Bell, Robert Elliott

Final Report

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DEVELOPMENT OF A PAVEMENT MANAGEMENT SYSTEM

TRC-9606

Final Report

Submitted to

Arkansas State Highway and Transportation Department

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16. Abstract The goals of the project were (1) to develop a multimedia based highway information system, and (2) to evaluate the current practice of pavement management at AHTD, make recommendations, and calibrate the application of a pavement management system (PMS) for the State of Arkansas. Part One of the report presents the development of a multimedia service that can be applied in a state highway department environment. This Multimedia-based Highway Information System (MMHIS) utilizes state-of-the-art technologies in digital video, high-speed networking, and the video server. A data-synchronization algorithm was developed to dynamically display digital video frames along with traditional engineering data sets that contain information such as as-built data, pavement condition and performance, traffic safety, geometric features, and other infrastructure data. Geo-referencing capabilities were also developed into MMHIS. Part Two of the report presents the calibration of dTIMS® for AHTD. The data collected with the ARAN vehicle is used as input values for the PMS software, dTIMS®. The calibration of dTIMS® focused on the Interstate and NHS (National Highway System) of Arkansas. The following tasks were completed in this research: (1) segmentation of highway sections, (2) development of traffic loading history, (3) development of necessary performance prediction curves, (4) setting up dTIMS® for optimization analysis, (5) documenting optimization runs for pavement rehabilitation with Arkansas data. Further updates as new data are collected is required for the PMS to be useful to the ATHD.					
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Project Abstract

The goals of the project were (1) to develop a multimedia based highway information system, and (2) to evaluate the current practice of pavement management at AHTD, make recommendations, and calibrate the application of a pavement management system (PMS) for the State of Arkansas. Part One of the Final Report covers the first area on the development of a Multimedia Based Highway Information System (MMHIS). MMHIS extends the capabilities of current photo logging facilities. Part Two of the Final Report covers the second area on the calibration of the existing PMS software, dTIMS. The two areas are within the activities of highway engineering and pavement management. However, due to the fact that the technical contents of the two areas do not overlap, the Final Report is divided into two separate parts.

Photographic logging systems used by highway agencies provide engineers with information in the analysis of traffic accidents, design improvements, and highway pavement management. However, there exist limitations for such systems in the areas of accessibility, search capability of the image library, and synchronization of the video data with traditional engineering site data. The analog nature of the video signals also presents difficulties in integrating the visual information with other types of data. Part One of this report presents the development of a multimedia service that can be applied in a state highway department environment. This Multimedia-based Highway Information System (MMHIS) utilizes state-of-the-art technologies in digital video, high-speed networking, and the video server. A data-synchronization algorithm was developed to dynamically display digital video frames along with traditional engineering data sets that contain information such as as-built data, pavement condition and performance, traffic safety, geometric features, and other infrastructure data. Geo-referencing capabilities were also developed into MMHIS, so that multimedia data is location-referenced in the databases. Finally, an operation guide for MMHIS is provided in the report.

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INTRODUCTION

Visual information is frequently used in highway departments for traffic engineering and infrastructure management. Another type of information is tabulated site data organized in traditional engineering databases on pavement history and layer information, pavement width/type, average daily traffic (ADT), accident history, and signing and marking inventory, and others. These two types of information (roadway images and traditional engineering database) can be of daily benefit to the needs of various divisions in state highway departments. In order to improve data accessibility in a highway department, it will be very beneficial to combine these two information sources into one comprehensive database that can be accessed simultaneously.

However, most existing photo logging systems used by various highway departments are analog based and located at specific location(s) within the department. Simultaneous multiple accesses to the video data are not possible. Searching for site data is cumbersome. Traditional engineering site data are contained separately from the video databases. There were a few studies in an effort to exploit new technologies to improve the accessibility and usability of video information collected from the photo logging process. Wang et al. [1] present general concepts and design issues for the development of a distributed multimedia based highway information system (MMHIS) and discussed the economic and technical feasibility of using digital video and new networking technologies for such a system. It was concluded in that study that the latest technology allows such a system to be developed cost-effectively. This report summarizes the studies in the areas of high-speed networking, video server technology, and data synchronization that are essential for the implementation of an MMHIS. It is demonstrated that a future digital video-based highway information system will be efficient and productive through use of technologies such as Asynchronous Transfer Mode (ATM) and state-of-the-art video server devices.

A working system has already been developed for the Arkansas State Highway and Transportation Department (AHTD). The system has a user intuitive interface. A guide on how to use this system is also given in this document.

HISTORY OF PHOTO-LOGGING SYSTEM AND BASIC REQUIREMENT OF MMHIS

Problems with Existing Photo-logging Systems

Current existing photo-logging systems use data collection vehicles to collect data on pavements and roadside structures and to take videos of the right-of-way. The video information used by highway agencies is stored in analog format and located at specific locations. The storage media include tapes, films, and laser disks. Engineering site data are stored in separate databases. Video playing devices are used to play the highway videos. This is shown in Figure 1. Special-purpose software is used in some existing systems to retrieve and present site data tables to the user. The data in the database, however, are not well organized. Some systems require the user to use general-purpose DBMS software to open the table and query information. Others use file processing instead of database management. The limitations of existing systems are exhibited in the areas of accessibility, search capability of the video library, and synchronization of video data with traditional engineering site data. Users who are interested in a section of a road when viewing the video have to go to another location to look for the corresponding site data. The existing systems also lack multiple-user access capability. Due to the analog nature of the video signals, it is difficult to integrate the visual information with computer databases. It is a time consuming process to look up and reassemble the video and site data in different formats and from various sources.

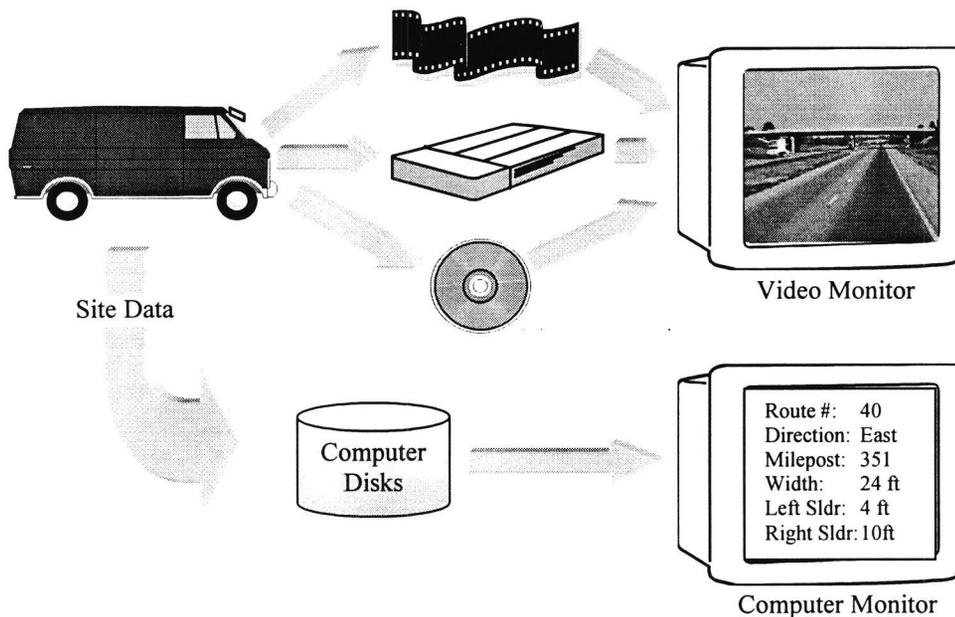


Figure 1 – The Existing Photo-logging System Data Flow

Basic Features of MMHIS

A new system – Multimedia-based Highway Information System (MMHIS) – was developed in this project to solve the problems in existing photo-logging systems. Technologies used in the new system include digital video, high-speed video server, ATM networking, relational database management system, and 3D-map rendering. MMHIS also uses a data synchronization algorithm to synchronize the highway motion video with the display of other data – engineering site data, roughness and rutting graphs, and location on the 3D-map. A high-speed network links workstations with the MMHIS server so users can look at the photo-logging video and the synchronized data sets without leaving their offices. Because the engineering site data are stored in computer databases, MMHIS can be easily customized to fit the need of different departments.

Apart from easy data accessibility, data presentation in MMHIS is more flexible than the old systems. An integrated environment hosts various views that are used to display data from various sources. The views can be customized to display a certain collection of fields in the data set. It can display the data in either categorized or user-defined format. Users can choose whether to use metric or imperial units in the data display. When using the user-defined format, the order of the data fields can also be customized.

With the technology advancement of satellite imagery and remote sensing, vast amount of 3D earth surface data is readily available. Because all inventory data from photo logging are location-specific and have spatial characteristics, a terrain visualization interface was constructed for MMHIS. Users can interact with a 3D digital map for the area of interest and visually select data queries from this map. This visualization interface allows users to rotate, zoom in and out, and pan around the terrain surface of the area. The picking operation for the 3D map was implemented using a specially designed picking algorithm. The 3D map can be rotated freely within a certain range. The picking algorithm guarantees that users can always click on the road in the rotated map and get the correct location information. The 3D-map shows the terrain surface relief when rotated to a low angle. In most cases, however, users view the map from a right angle. In such cases, MMHIS uses special algorithms to render the map so that the zooming, panning, and rendering operations can be conducted with a very fast speed.

The Querying database in MMHIS is object-oriented. There are several different ways to conduct a query in MMHIS. It does not require users to be familiar with any general-purpose DBMS products. Users need only to specify the location on a road by specifying the route number, direction, and milepost, or by clicking on the map offered by MMHIS. MMHIS provides highway engineers an efficient and effective tool in analyzing road and roadside structures with instant accessibility to the multimedia databases. This tool is not available to any highway department in the United States at this time. The core technologies developed for this system can be used in future generations of highway information systems in any highway department.

NEW TECHNOLOGIES OF DIGITAL VIDEO AND GEO-REFERENCING

Digital Video for MMHIS

The video quality associated with consumer TV and video tapes, including video from Super VHS and laser disks, is determined by the analog video standards set by the National Television Standard Committee (NTSC) in the early 1950s. Even though an analog video signal can be transmitted and copied through narrow bandwidth, it is difficult to manipulate, copy, and distribute without introducing electronic noise into the original signal, resulting in the deterioration of image quality. Without the use of high-end video production equipment, the integration of analog video with other types of data, such as text and graphics, is very difficult.

Additionally, in an MMHIS, multiple users need simultaneous and random access to video data. For data stored in an analog system, multiple and unsynchronized access to video data is a problem. For instance, it is difficult to view two different sections of the same videotape simultaneously, and then decide to freeze one while running the other. Routing of multiple analog video data to users is also complicated. If the video signal is presented in digital format, like the digital sound in compact disks, it can provide much better image quality, can be easily duplicated and can be incorporated into other media without introducing artifacts or losing fidelity. Because digital video data is stored in disk files, it is possible to allow simultaneous multiple accesses to the same digital video files through computer networks. Digital video is necessary when high fidelity, fast and multiple user accesses are required of the MMHIS.

Data Collection, Compression and Decompression (CODEC)

Presently the visual data is collected in a vehicle, such as a van, with video capturing equipment. Normally, the visual data is recorded onto a Y/C signal based tape (S-VHS or Hi-8mm) or laser disk. The video signal is analog based with luminance and chrominance information separated. The perceivable vertical resolution of the video data is about 400 lines. The recorded media are then categorized for viewing in the office. To prepare the video for the MMHIS, the analog based video data is digitized and becomes digital data sets that are directly manageable with computers. The digital video is generated through a process called encoding with source video data, such as tapes. One full color (8-bit for each of red, green, and blue) digital image with a NTSC TV resolution (640 x 480) requires approximately 0.92 megabyte of data storage, resulting in about 27 megabytes of storage space for one second of motion video. In addition, the input and output bandwidth of modern microcomputers are not generally capable of processing this amount of data per second. Therefore, data compression is needed to reduce data storage requirements on the one hand, and to improve the data flow rate on the other.

The amount of compression ranges from 2:1 to 200:1, depending on the type of algorithm, the implementation of the algorithm, the level of video quality, and the presence of hardware assistance. Most compression algorithms are “lossy”, meaning that

some information is lost during the compression of the data, due to the fact that the compression ratio based on lossless encoding algorithms is low, around 2:1. The objective for most applications is to retain visually faithful representations of the original images and discard any visually insignificant information. The process of compression and decompression (for playback) is called CODEC for encoding and decoding. Some approaches require more operations to be performed in encoding than in decoding. This type of CODEC is referred to as asymmetrical. If both processes require the same amount of processing, it is called symmetrical CODEC.

Motion JPEG (Joint Photographic Experts Group) and MPEG (Motion Picture Experts Group) are the two dominant types of digital video CODECs, both of which are used in this MMHIS research. The Joint Photographic Experts Group (JPEG) developed the JPEG compression algorithm for still images based on Discrete Cosine Transformation (DCT), the quantization approach and Huffman encoding. The standard was then widely adopted as Motion JPEG for video sequences, each frame of which is compressed based on the JPEG standard. Motion JPEG allows easy random access to any frame in a digitized sequence. Compression for Motion JPEG is conducted exclusively on redundant data in individual frames without condensing any data between frames. Hardware based JPEG CODEC's can capture full-screen, 30 frame per second video in real time. When a high compression ratio (over 20:1) is not required, this symmetrical CODEC is very effective in preserving the details and fidelity of single video frames.

Unlike JPEG, which condenses information only within each frame, the standard developed by the Motion Picture Experts Group, MPEG, compresses information based on data within a frame and frame to frame motion. It should be noted that the compression within frames in MPEG is also based on DCT and related algorithms.

MPEG allows compression ratios over 100:1 while still retaining good visual quality. Due to its high compression ratio, MPEG is a desirable delivery format for applications that require narrow bandwidth transmission, such as CD-ROM and video networks. However, due to the asymmetric nature of MPEG, the encoding process requires very high computing power. For example, a state-of-the-art MPEG encoding device can consist of over a dozen RISC based compression processors. The decoding process of MPEG needs relatively less computing power. At similar levels of video quality, a Motion JPEG stream will require a much higher data rate than an MPEG compressed stream. Current available MPEG systems are classified into the categories of MPEG1 and MPEG2 with MPEG1 being used for CD storage and the Internet, and MPEG2 being used for studio quality video and satellite digital TV systems.

Geo-referencing Technologies

The 3D map interface of the MMHIS uses a geo-referenced map to show the location of the video on the map and allows users to query data on any point on the map. The information about the location of any point on the map is displayed in a pop-up window when the point is clicked with the right button of the mouse. In addition, if the

clicked point is near a road, the route number, direction, and milepost of the road at that point are also shown.

The 3D map of MMHIS is rendered based on information stored in the 3D-map database. Separate files are used to store different data in the 3D-map database. These files are listed in Table 1.

Database File	Description
DEM	The digital elevation model that is used by MMHIS to render the terrain surface
2D surface map	3D map viewed from a right angle
2D coordinate maps	Coordinate maps that are used for 2D picking operations
2D zoom surface map	Map used to show the zooming interface
2D zoom coordinate maps	Coordinate maps that are used for zooming interface picking operations
Raster map	Map that shows surface features
Shape	Rendered shading for the terrain surface
Location	File that stores route number, direction, and milepost information

Table 1 – MMHIS 3D Map Databases

3D Database File Structures

Digital Elevation Models (DEM) are essential to the rendering of the 3D surface of the earth. The DEMs used in the MMHIS were obtained from the United States Geological Survey (USGS). They were then converted to MMHIS specific file formats to provide for fast information retrieval. The conversion is based on the understanding of the original USGS DEM file format. Several utility programs were developed to aid this conversion. The USGS DEM file format is a general format that is suitable for a variety of different DEMs. Because MMHIS only uses one type of DEM, it makes sense to simplify the file format and make access to the data more efficiently. In the mean time, the file size can be reduced to the minimum size possible and hence save storage space on the host computer. Twenty-four 1-degree DEMs are needed to cover the whole State of Arkansas. Instead of using 24 separate DEM files as the data source, MMHIS combined all 24 DEM files into one file. There are three different records in the combined DEM file. The first record stores the origin of the area that is covered by the DEM. It contains two floating-point numbers representing the longitude and the latitude of the origin (southwest corner coordinates) in degrees. The second record contains integers representing the number of grid points along both the longitude and latitude lines. The third record contains the elevations in meters along the profiles organized from south to north and from west to east. The numbers are stored in the internal integer format of the host operating system.

The rendering of a 3D map is time consuming on high-end desktop computers. Users of MMHIS normally want to scan the whole map quickly, locate the spot on the map, and then decide to see details of the terrain surface of that particular area of interest. To reduce the time for rendering the map and still offer the power to show the 3D-terrain surface, MMHIS treats the special case of 2D rendering separately. This requires a

separate database to be setup to store the 2D surface map. Windows has powerful Device-Independent Bitmap (DIB) manipulation API functions built in. To take advantage of that, MMHIS stores the 2D surface map in Windows DIB format.

The 2D coordinate maps are saved in two files—one for longitude, one for latitude. These files are used to implement the picking operation in 2D special cases. The longitude and latitude of any point on the map can be identified by querying the above two files.

The 2D zoom surface map is similar to the 2D surface map file. It is used to speed up the zooming control in the MMHIS's map interface. The file is in Windows DIB format. The 2D zoom coordinate maps are similar to the 2D coordinate maps. These files are used in the zooming control to implement the picking operation.

The raster map of Arkansas is used in a texture mapping process to project the 2D map to the 3D-terrain surface. This file records the intermediate result of this mapping. The file contains three records. The first record stores the origin of the area. Two floating-point numbers are used in this record to give the longitude and the latitude of the origin. The second record stores the number of grid points along the longitude and latitude lines. The file uses the same grid system as the DEM. The third record stores the texture mapping results. It is an array of red, green, and blue (RGB) values ordered along the grid lines from south to north, west to east. Each RGB value contains three bytes that represent the mapped red, green, and blue color element on that grid point.

MMHIS renders the 3D-terrain surface with different shades, showing the shape of the surface with light effects. With real-time rendering, the shading process is very slow. Because the terrain surface shape is fixed, the shading of all points in the area is saved to an intermediate file so that the data do not have to be generated each time the scene is rendered. The shape information file is used for this purpose. The file's structure is similar to the raster map information file. The only difference is that instead of saving an array of three bytes representing RGB values in the third record, this file saves a byte array. Each element of the array represents the corresponding shading of the grid points.

Note that this file does not record things such as hidden surface information. MMHIS deals with the issue of hidden surface removal using other tools. To show 3D objects' positions, real-time rendering is conducted when the map is displayed. The real rendering process uses a less computation-intensive lighting model so that the scene can be efficiently rendered.

The route numbers, directions, and mileposts of grid points on roads are saved in the location file. MMHIS uses this information to decide the query location of a point on the map. There are three records in this file. The first two records are the same as those in the shape information file. The third record contains an array of integer pairs representing the route and milepost of each grid points. The route is the RowID field value in the state master table (refer to later sections for database structures).

Generating the 3D Map Database

The conversion from USGS 1-degree DEMs to the MMHIS DEM file requires two steps, utilizing two special utility programs developed specifically for this purpose. These two programs are not built into the MMHIS integrated environment because the conversion takes place only once. The first step converts individual USGS 1-degree DEM files into individual MMHIS DEM files using a vertical scale factor of one. The second step combines these small files into the final large DEM file.

The 2D surface map is a special case of viewing the 3D surface map from the right angle. The 2D surface map is generated by rendering the 3D surface map using the right angle. It is saved in the DIB format to the 2D surface map file.

The 2D coordinate maps are rendered using the more general technique of rendering the 3D coordinate map with a viewing angle of 90° (right angle). The rendered map is saved in the DIB format to the 2D coordinate map files.

The process of creating these two files is the same as the process of creating the 2D surface map and the 2D coordinate maps; with the use of different parameters. The resultant files are saved to appropriate files.

MMHIS uses a 2D map that was scanned from a paper map as the basis for the features of the 3D map. Information from the 2D map is used in the final rendering of the 3D map. It is also used in the road digitizing process. The resolution of this map is smaller than the resolution offered by the DEM.

The creation of the raster map involves a texture mapping (or projection) process. The projection algorithm is described below.

- Loading the 2D map and the DEM

This step loads the 2D map into memory. The raw data of the image is separated to simplify the projection process. The MMHIS DEM file is also loaded for use in the rendering process.

- Matching the 2D raster map with the MMHIS rendered region

In this step, the longitude and latitude lines are rendered and overlaid to the 2D map. The purpose is to find out the correct transformation factors so that the rendering results match the corresponding lines on the 2D map. During the matching process, transformation factors are interactively adjusted and the longitude and latitude grids are rendered after each adjustment. The result is shown on screen and is visually compared with the lines on the 2D map. The process stops after a satisfactory match is reached.

- Rendering the 3D-terrain surface using lighting effects

Using the results from the previous step to conduct the transformation, the 3D-terrain surface is then rendered to a buffer that has the same dimension as the

2D-raster map. Because of the large size of the area, a memory mapped file kernel object is used as the virtual memory for the rendering buffer. DEM data are used in this step.

- Reading the DEM records and match each grid points to the results in the previous two steps

In this step, the DEM records are scanned and the view-port coordinates for the grid points are calculated with the OpenGL raster position functions. The view-port coordinates are used to get the colors of corresponding pixels in both the 3D-terrain surface rendering buffer and the 2D-raster map. These colors are used to fill the records of the raster map and shape information files.

Roads on the 2D-raster map are digitized and saved in the location information file. The digitization is an interactive process. The following steps are used in this process.

- Prepare the 2D-raster map and the longitude and latitude grid buffers

The digitization process uses the 2D-raster map to show the location of roads. It requires the user to interactively specify points on the road on the 2D-raster map. The map is loaded into one buffer of the program. Two other buffers containing the corresponding longitude and latitude grid information can either be rendered directly or loaded from disk files (if one has already been created). These two buffers are used to get the grid coordinates of points on the 2D-map.

- Define points of a new road

A temporary file is created in this step to save the coordinates of points on the road. The program checks for mouse click messages after the above file is created. The points clicked by mouse are then linked to form a line representing the road. Because points clicked by the mouse does not cover all points on the road, Windows dynamic data analysis function `::LineDDA()` is called to retrieve all pixels on the road. The view-port coordinates of all pixels on the road are saved into the temporary file.

- Correlate mileposts with grid coordinates

The coordinates saved in the above file are checked against the pixel information in the two grid coordinate buffers to get the longitude and latitude of the points. The results are saved in the same file.

- Specify mileposts for key points

Similar to the video frame index building process, this step allows users to interactively specify the milepost of certain points (called key points) on the road. These points will be matched exactly to the mileposts specified.

- Update database

Linear stretch is used to calculate the mileposts of every grid points and the result is saved in the last two fields of the fixed data table corresponding to the road.

Picking Operations

The map module allows users to click on the map and shows a small popup window with location information in it. If the point clicked is a point on a highway section and is registered in the database, it also displays a menu showing the point's corresponding route number, direction, and milepost. The operation is called *picking*. The picking can happen anywhere on the map.

MMHIS creates two buffers for picking operations. Instead of rendering the same scene to two different buffers and specifying the names of the objects, the MMHIS renders the main scene only once. The MMHIS specific C++ class `cmaptools` handles rendering the picking buffers in a simplified way—it renders the location information directly into the picking buffers. `cmaptools` does not use name stacks as normal OpenGL programs do. It uses *colors* to represent longitude and latitude grid numbers in its picking buffers. When a point on the map is clicked by the user, the corresponding two points in the two picking buffers are checked. The coordinates of the clicked point can be obtained by decoding the colors of the corresponding points in the picking buffers. This decoding process is the reverse of the rendering process. `cmaptools` does not use any lighting effects when it renders the picking buffers. This ensures the color of each pixel in the picking buffer is the one specified during the rendering process. The `cmaptools` does not render anything on the screen. This ensures that the actual color depth of the display device does not affect the color depth requirement of the picking buffers. Figure 2 shows MMHIS's picking mechanism.

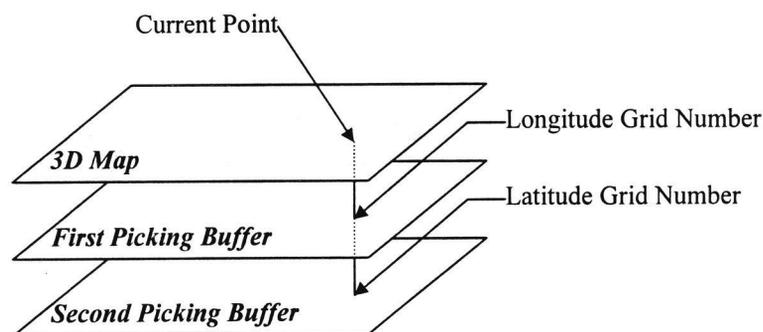


Figure 2 – Picking Operations

After the coordinates of a point on the map are obtained, MMHIS obtains the elevation of the point from the DEM data file and displays the location information in a small pop-up window. The program then checks all the points in the vicinity using the data in the location information file. The route (represented by the `RowID` field of the

state master table) and milepost can be obtained from this file if the point is registered in the digitizing process. With this information in hand, the direction information can be queried out from the state master table. The returned data is used to construct a context menu to show the position of the point.

Location Synchronization with Video and Site Data

When a query is going on, a location indicator (a small flashing red dot) is displayed on the map to show the current vehicle location. The location indicator goes along the highway on the map as the video plays. The synchronization timer handler queries the current vehicle location from the fixed data table and passes the query result to the 3D-map sub-module. The map module then finds the screen coordinates of the current vehicle location. MMHIS maintains a 3D position in window coordinates. (This is handled internally by the OpenGL engine.) This position, called the *raster position*, is used to position pixel and bitmap write operations. It is maintained with sub-pixel accuracy. The current raster position consists of three window coordinates (x, y, z), a clip coordinate value (w), an eye coordinate distance, a valid bit, and associated color data and texture coordinates. The w coordinate is a clip coordinate, because w is not projected to window coordinates. MMHIS converts world coordinates to window coordinates by calling appropriate API functions. The converted window coordinates are used to display the location indicator on the map.

The Preparation of Video Frame Index

Video frame indexes were created with the MMHIS Index Building module. The index building process is divided into the following steps.

- Obtaining information. In this step, necessary information is collected in the *Building Index* dialog box. The fields are listed in Table 2.

Field	Explanation
Video File Name	The name of the video file for which frames will be indexed
Video Start Frame	Frame number corresponding to the beginning milepost
Video End Frame	Frame number corresponding to the ending milepost
Route Number	Route number of this section
Direction	Direction of this section
Start Milepost	Starting point of this section
End Milepost	End point of this section
Key points	Mileposts of points that corresponds to known frame numbers
Turning points	Destination route numbers, directions and mileposts of turning points

Table 2 – Index Building Module Input

- The key points specified by the user are used to define subsections of the highway section covered by the current video. Each subsection begins at one key point and ends at the next key point. That is, in each subsection only the first milepost and the last milepost have corresponding video frame numbers specified. Video frame numbers corresponding to the rest of mileposts are calculated by using the linear interpolation method. The speeds of the vehicle when it took the video are recorded into the main data table. The speed data are used as the determining factors.

The above method guarantees that key points are exactly indexed with the frame number specified. This is especially useful when the speed data is not accurate enough to be used as the sole factor to interpolate values. If the total accuracy is guaranteed, only the starting point and end point of the whole section need to be defined as key points.

To describe the above algorithm mathematically, suppose for a subsection the starting milepost is s , which corresponds to frame number fs , and the end milepost is e , which corresponds to frame number fe . The number of mileposts in this subsection n can be calculated as

$$n = \frac{e - s}{step} + 1,$$

in which *step* is the distance between consecutive mileposts. In the current database, the value of *step* is 25 meters. Suppose the speed value for milepost *i* (*i* is 1 – *n-1*) is *speed(i)*. The corresponding frame number is *frame(i)*. The traveling time for the video to cover this subsection *T* is calculated as

$$T = \sum_{j=1}^{n-1} \frac{step}{speed(j)}.$$

The frame numbers for the rest of mileposts are calculated as

$$frame(i) = \frac{(fe - fs)}{T} \sum_{j=1}^i \frac{step}{speed(j)} + fs.$$

Database updates are involved in the index building module. Because the Microsoft Access ODBC driver supports database updates, it is just a simple matter of calling the appropriate update functions with proper SQL commands to finish building the index. The index building process is shown in Figure 3.

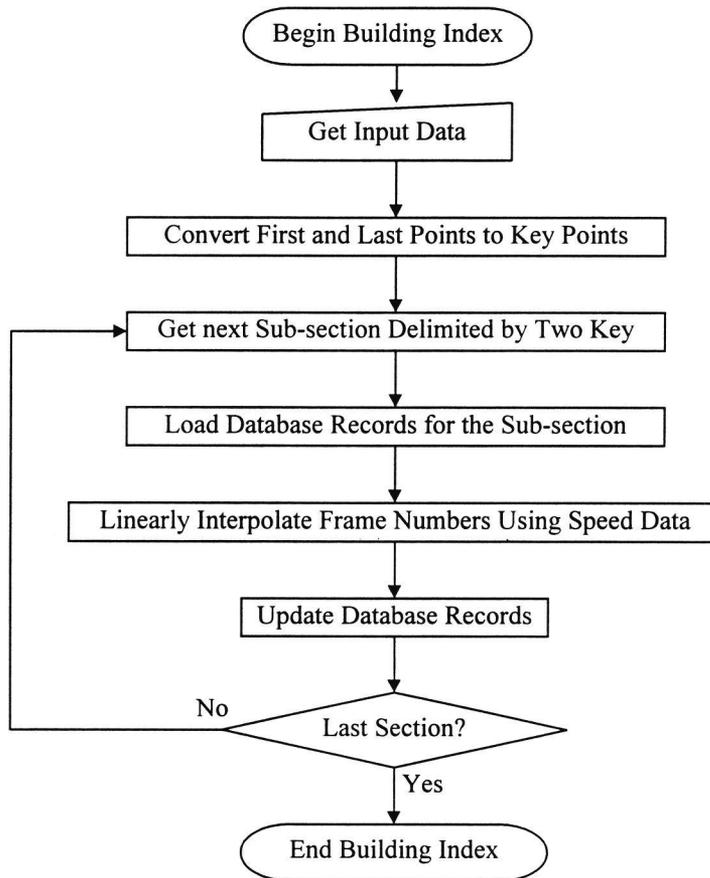


Figure 3 – Index Building Flowchart

The Synchronization of Video and Site Data Display

When MMHIS is started with a query, the information displayed is all synchronized. That is, when the video is playing, data displayed in all other windows change dynamically with the video frames. The view window of the MMHIS control module has a timer set up at creation time. This timer, called the *synchronization timer*, is used to synchronize the display of site data with the video. The synchronization timer handler in the MMHIS control module does not actually find the correct data and display them. Instead, it acts as a director to orchestrate all sub-modules of MMHIS.

The synchronization process uses a frame range to check if the current frame of the video is still in the range for the current milepost. The range is updated when the site data and the video frame are synchronized. The first time a query is started, this range is set to an impossible range to guarantee that the synchronization operation is applied upon initialization. The synchronization process is shown in Figure 4.

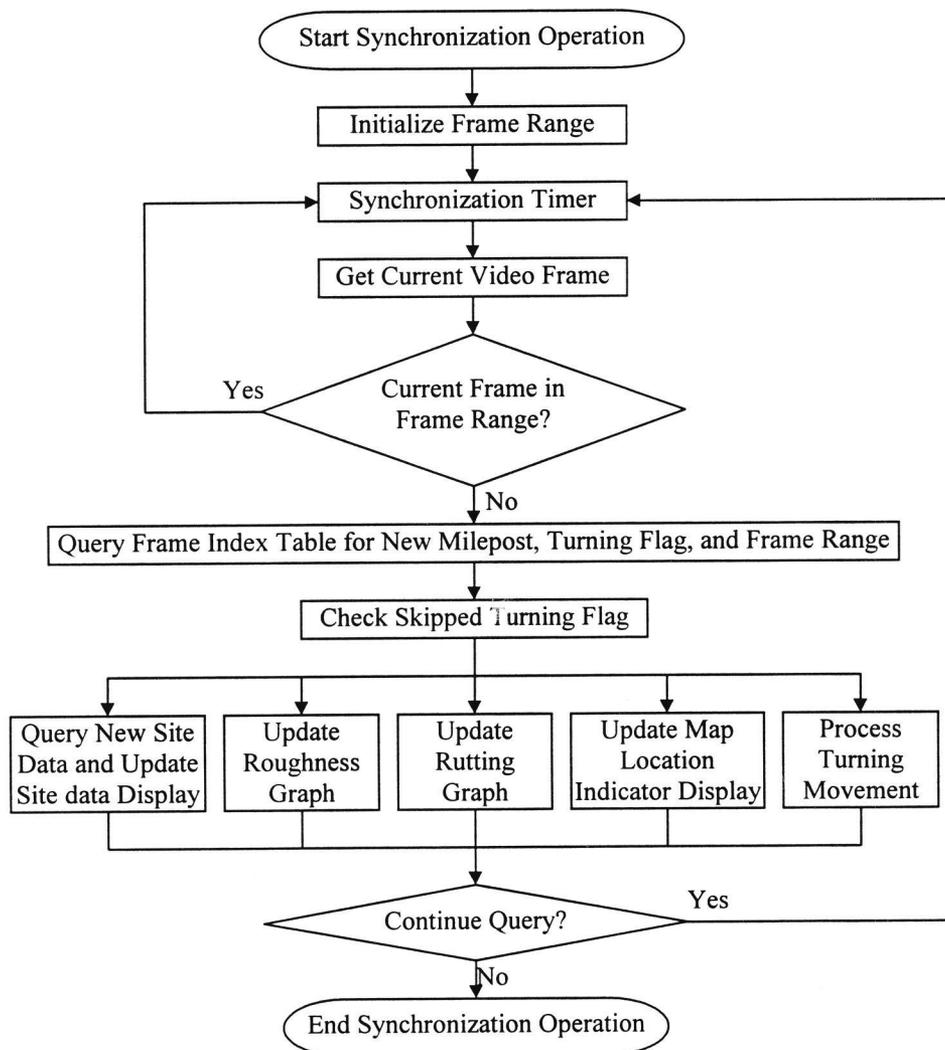


Figure 4 – The Synchronization Process Flow Chart

DATABASE STRUCTURES OF MMHIS

There are four database layers in the MMHIS. The first layer contains the state registration table. The second layer contains the state master table. The third layer contains tables that store engineering site data, frame index, turning movement information, and the data display format. The fourth layer contains the yearly data table. These tables are used to store data collected in different years for the roads. This layered structure is shown in Figure 5.

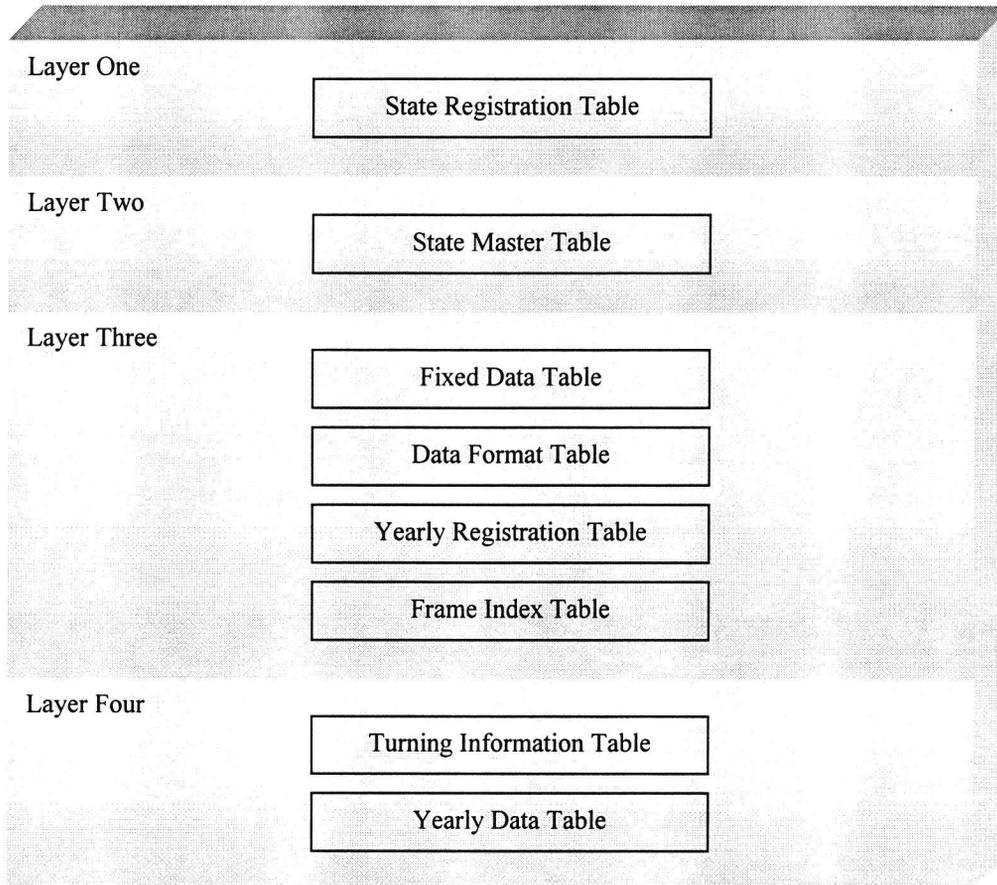


Figure 5 – The Layered Database Structure For MMHIS

The State Registration Table

The state registration table is used to register all the states in the US. Each state has a record in this table. The structure of this table is listed in Table 3. The primary key for this table is StateName. The field StateMasterTableExist determines if a corresponding table (state master table) in the second layer exists for the state. Other fields specify the map database (which is saved separately from the database for engineering site data), and basic attributes of the map.

Field Name	Data Type	Short Description
StateName	Text	State Name
StateShortName	Text	Abbreviation of State Name
StateMasterTableExist	Boolean	Yes if the state has a master table; No if not.
MapPath	Text	Path for all the files relating to map rendering
DemFileName	Text	Name of the digital elevation modal file
MapFileName	Text	Name of the raster map file
ShapeFileName	Text	Name of the rendered terrain shape file
LocationInfoFileName	Text	Name of the file that contains location information
FlatMapFileName	Text	Name of the 2D map file
FlatXFileName	Text	Name of the 2D x-coordinate file
FlatYFileName	Text	Name of the 2D y-coordinate file
ZoomMapFileName	Text	Name of the zoom map file
ZoomXFileName	Text	Name of the zoom x-coordinate file
ZoomYFileName	Text	Name of the zoom y-coordinate file
InitZoom	Number	Zoom factor for the whole state
InitCenteri	Number	Initial x-coordinate of the center point
InitCenterj	Number	Initial y-coordinate of the center point
FlatMapWidth	Number	Width of the 2D map
FlatMapHeight	Number	Height of the 2D map

Table 3 – The Structure of State Registration Table

The State Master Table

The state master table registers all the roads in the corresponding state. Each record in this table represents a unique route. The structure of this table is shown in Table 4. The field RowID (RoadID attribute of the entity ROAD) is the primary key for this table. The values of RouteNumber and Direction can also uniquely identify a record in this table. They are also used as keys for this table. Other fields represent the existence of other tables in the third layer.

Attention should be paid to the DatabaseFileName field. This field specifies the actual database that hosts the corresponding tables in the third layer. As pointed out later, the MMHIS uses Microsoft Access® DBMS as the physical implementation platform of the database system. The Microsoft Access database has a limitation on the number of tables in each database. Putting all of the tables in one database may cause problems since the total number of tables may well exceed the limit.

Including the VideoFilePath field allows the system to put video files for different states to different locations and makes it easier to manage the video files.

Field Name	Data Type	Short Description
RowID	Number	Record serial number
RouteNumber	Text	Route number
Direction	Text	Direction
FromMilePost	Number	Start milepost of the road
ToMilePost	Number	End milepost of the road
FixedDataTableExist	Boolean	The existence of the fixed data table
FrameIndexTableExist	Boolean	The existence of the frame index table
TurningMovementTableExist	Boolean	The existence of the turning movement information table
YearDataRegistrationTableExist	Boolean	The existence of the yearly data registration table
SiteDataFormatTableExist	Boolean	The existence of the site data format table
DatabaseFileName	Text	Database file name for all the above mentioned tables
VideoFilePath	Text	Path for the video files for the current route

Table 4 – The Structure of the State Master Table

Fixed Data Table

This table stores the basic information for each route. The data stored in the table normally remain the same for a certain period of time. The table only stores the latest values for the fields. The fields LongitudeGrid and LatitudeGrid are used to store the spatial location for each milepost. This is used in the MMHIS to mark the location of the current point on the map. In this table, the MilePost field is the primary key. The structure of this table is listed in Table 5.

Field Name	Data Type	Short Description
MilePost	Number	Milepost
Lane	Number	Number of lanes
PavementWidth	Number	Total width of the pavement
LeftShoulder	Number	Width of the left shoulder
RightShoulder	Number	Width of the right shoulder
District	Text	District
Area	Text	Area
Region	Number	Region
ADT	Number	Average daily traffic
ADL	Number	Average daily load
GrowthFactor	Number	Growth factor
StructureNumber	Number	Structure number of the pavement
Project	Text	Project
Year	Number	Year
Layer1	Text	Layer 1 Material
Thickness1	Number	Thickness of Layer 1
Layer2	Text	Layer 2 Material
Thickness2	Number	Thickness of Layer 2
Layer3	Text	Layer 3 Material
Thickness3	Number	Thickness of Layer 3
Layer4	Text	Layer 4 Material
Thickness4	Number	Thickness of Layer 4
Layer5	Text	Layer 5 Material
Thickness5	Number	Thickness of Layer 5
Layer6	Text	Layer 6 Material
Thickness6	Number	Thickness of Layer 6
Rate	Number	Rate
Speed	Number	Speed of the vehicle when the data was collected
LongitudeGrid	Number	Longitude coordinate of the current point
LatitudeGrid	Number	Latitude coordinate of the current point

Table 5 – The structure of fixed data table

The Data Format Table

The table contains information on the format of the site data display. Users can modify the contents of this table to change the output format of the site data. The primary key for this table is `FieldName`. The values of this field correspond to the fields in the fixed data table and the yearly data table (mentioned later). MMHIS can use two unit systems to display site data. To allow users to decide what to display for the units, several fields are included in this table specifying the name of the unit and the conversion factor for the unit. The structure of this table is listed in Table 6.

Field Name	Data Type	Short Description
FieldName	Text	Field name in the database tables
Caption	Text	Field caption shown in the site data view
Type	Text	Data type of the current field
Unitless	Boolean	Whether or not the field has a unit
MetricsUnitName	Text	Unit name for the field when metric unit system is chosen
MetricsConverter	Number (single)	Multiplier for converting the field value to metric system values
ImperialUnitName	Text	Unit name for the field when imperial unit system is chosen
ImperialConverter	Number (single)	Multiplier for converting the field value to imperial system values
Format	Text	Format specifier for the field data
GroupName	Text	Name of the category to which the current field belongs
DefaultDisplayOrder	Number (integer)	Default order to display the fields
SourceTable	Text	Name of the table to which the current field belongs

Table 6 – The Structure of the Data Format Table

The Frame Index Table

The frame index table contains the synchronization information that is used to synchronize the site data display with the video display. The MilePost field is used as the primary key for this table. Since on the Windows NT ® operating system there is a limit on the size of video files, multiple video files are normally needed for a road. The VideoFileName field is used to store the file names for the videos. The structure of this table is shown in Table 7.

Field Name	Data Type	Short Description
MilePost	Number (long integer)	Milepost
VideoFileName	Text	Name of the video file
StartFrameNumber	Number (long integer)	Start frame for the current milepost
EndFrameNumber	Number (long integer)	End frame for the current milepost
TurningMovementFlag	Number (byte)	Flag for turning movement

Table 7 – The Structure for the Frame Index Table

The Turning Movement Information Table

The turning movement information table contains information on the location and destination of turning points. The structure of this table is shown in Table 8.

Field Name	Data Type	Short Description
MilePost	Number (long integer)	Milepost
LeftState	Text	Left turn destination state
LeftRowID	Number (long integer)	Left turn destination route
LeftMilePost	Number (long integer)	Left turn destination milepost
ThroughState	Text	Through destination state
ThroughRowID	Number (long integer)	Through destination route
ThroughMilePost	Number (long integer)	Through destination milepost
RightState	Text	Right turn destination state
RightRowID	Number (long integer)	Right turn destination route
RightMilePost	Number (long integer)	Right turn destination milepost

Table 8 – The Structure of the Turning Movement Information Table

The Yearly Registration Table

The year registration table has one record for each year that has yearly specific data. Each record in this table has a corresponding table in the fourth layer. The structure of this table is listed in Table 9.

Field Name	Data Type	Short Description
Year	Text	The year number
LogFromMilePost	Number (long integer)	Starting log milepost
LogToMilePost	Number (long integer)	End log milepost

Table 9 – The Structure of the Yearly Registration Table

The Yearly Data Table

The yearly data table contains each year's data. The structure of this table is shown in Table 10.

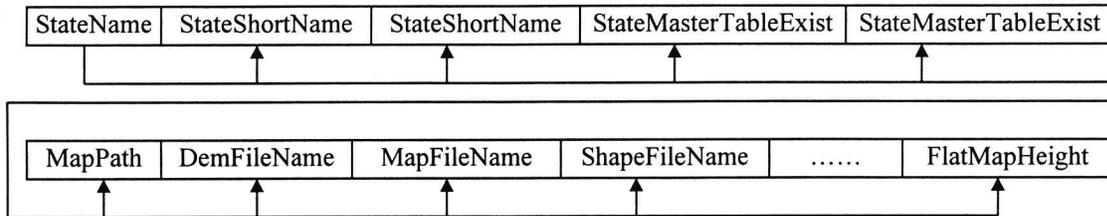
Field Name	Data Type	Short Description
MilePost	Number (long integer)	Milepost
Cracking	Number (single)	Cracking value
RoughnessLeft	Number (single)	Left wheel roughness
RoughnessRight	Number (single)	Right wheel roughness
M	Number (integer)	Field taken from Arizona database
RuttingLeft	Number (single)	Left wheel rutting
RuttingRight	Number (single)	Right wheel rutting
Patching	Number (integer)	Patching
Flushing	Number (single)	Flushing
ADT	Number (long integer)	Average daily traffic

Table 10 – The Structure of the Yearly Data Table

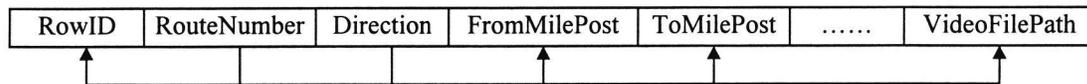
Functional Dependencies of Databases

The functional dependencies are shown in Figure 6. The above database schema design conforms the normalization criteria 1NF, 2NF, and 3NF. It has dependency preserving and lossless join properties.

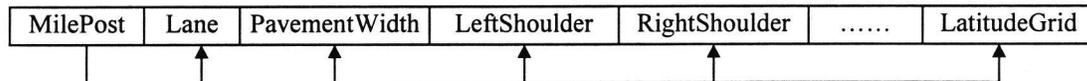
State Registration Table



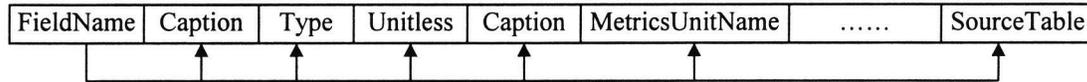
State Master Table



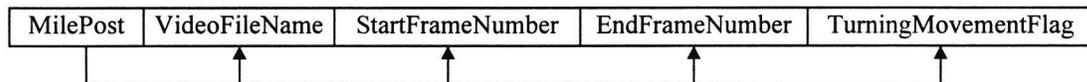
Fixed Data Table



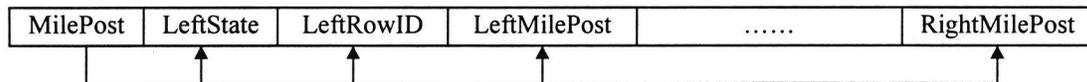
Data Format Table



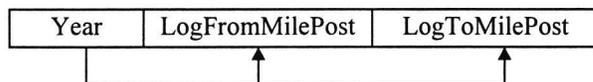
Frame Index Table



Turning Movement Information Table



Yearly Registration Table



Yearly Data Table

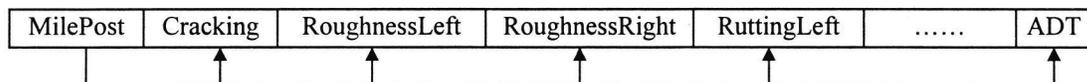


Figure 6 – Functional Dependencies of Databases in MMHIS

Database Indexes

MMHIS uses database indexes to speed up queries. The primary key in each table is automatically indexed. Additional indexes are added to each table according to the needs of queries. The indexes for the database tables in MMHIS are shown in Table 11 – Table 18.

Index Name	Field Name	Sort Order	Primary	Unique	Ignore Nulls
PrimaryKey	StateName	Ascending	Yes	Yes	No
StateShortName	StateShortName	Ascending	No	Yes	No

Table 11 – State Registration Table Indexes

Index Name	Field Name	Sort Order	Primary	Unique	Ignore Nulls
PrimaryKey	RowID	Ascending	Yes	Yes	No
RouteNumber	RouteNumber	Ascending	No	No	No
RouteNumberAndDir	RouteNumber	Ascending	No	No	No
	Direction	Ascending			

Table 12 – State Master Table Indexes

Index Name	Field Name	Sort Order	Primary	Unique	Ignore Nulls
PrimaryKey	MilePost	Ascending	Yes	Yes	No
LatitudeGrid	LatitudeGrid	Ascending	No	No	No
LongitudeGrid	LongitudeGrid	Ascending	No	No	No

Table 13 – Fixed Data Table Indexes

Index Name	Field Name	Sort Order	Primary	Unique	Ignore Nulls
PrimaryKey	FieldName	Ascending	Yes	Yes	No
DefaultDisplayOrder	DefaultDisplayOrder	Ascending	No	Yes	No

Table 14 – Data Format Table Indexes

Index Name	Field Name	Sort Order	Primary	Unique	Ignore Nulls
PrimaryKey	MilePost	Ascending	Yes	Yes	No
EndFrameNumber	EndFrameNumber	Ascending	No	No	No
StartFrameNumber	StartFrameNumber	Ascending	No	No	No
VideoFileName	VideoFileName	Ascending	No	No	No
VideoAndFrame	VideoFileName	Ascending	No	No	No
	StartFrameNumber	Ascending			
	EndFrameNumber	Ascending			
MilePostAndFrame	MilePost	Ascending	No	No	No
	StartFrameNumber	Ascending			

Table 15 – Frame Index Table Indexes

Index Name	Field Name	Sort Order	Primary	Unique	Ignore Nulls
PrimaryKey	MilePost	Ascending	Yes	Yes	No

Table 16 – Turning Movement Information Table Index

Index Name	Field Name	Sort Order	Primary	Unique	Ignore Nulls
PrimaryKey	Year	Ascending	Yes	Yes	No

Table 17 – Yearly Registration Table Index

Index Name	Field Name	Sort Order	Primary	Unique	Ignore Nulls
PrimaryKey	MilePost	Ascending	Yes	Yes	No

Table 18 – Yearly Data Table Index

NETWORK AND HARDWARE ISSUES IN A PRODUCTION ENVIRONMENT

MMHIS Network Performance Requirements

A single digital video stream based on the National Television Standard Committee (NTSC) standard has a data rate of about 200 kilobytes per second for MPEG1, 0.5 to 2 megabytes per second (MB/s) for most MPEG2 signals, and 3 to 5 MB/s for Motion JPEG. Common networks based on Token Ring or Ethernet have the shared data bandwidth of 16M bit/sec and 10 M bit/sec (2 MB/s and 1.25 MB/s) respectively. The effective actual bandwidth available to a station can be much less than the specified rate of 16 Mb/s or 10 Mb/s, due to (1) the nature of bandwidth sharing for both Ethernet and Token Ring, (2) network overhead. In addition, the two types of networks are optimized for carrying packet and burst data, and do a poor job of carrying full-motion video that requires guaranteed bandwidth. In order to provide multiple streams of video data (more than 10), the throughput of the traditional network needs to be improved and the bandwidth for individual stations needs to be guaranteed. Furthermore, it is required that video streams be delivered in a particular order with very small and consistent latency. Otherwise, frame drop and un-synchronization would occur. Ethernet, Token Ring, and Fiber Distributed Data Interface (FDDI) use shared-medium and are not capable of carrying motion video in a timely fashion. Therefore, the challenge is to design a proper network to both provide high bandwidth and guarantee video delivery.

The MMHIS capable computer network should be able to carry a number of services, including low speed data transmission for regular data sets and mail, medium speed data transmission for CAD design files, and high speed data transmission for the distribution of high quality video footage of highway sections. Therefore, the network system cannot be designed specifically for one service. Figure 7 shows a range of services with an estimated bit rate of a few bit/s up to some hundreds of Mb/s. The holding times (continuous transmission period) vary from seconds to hours.

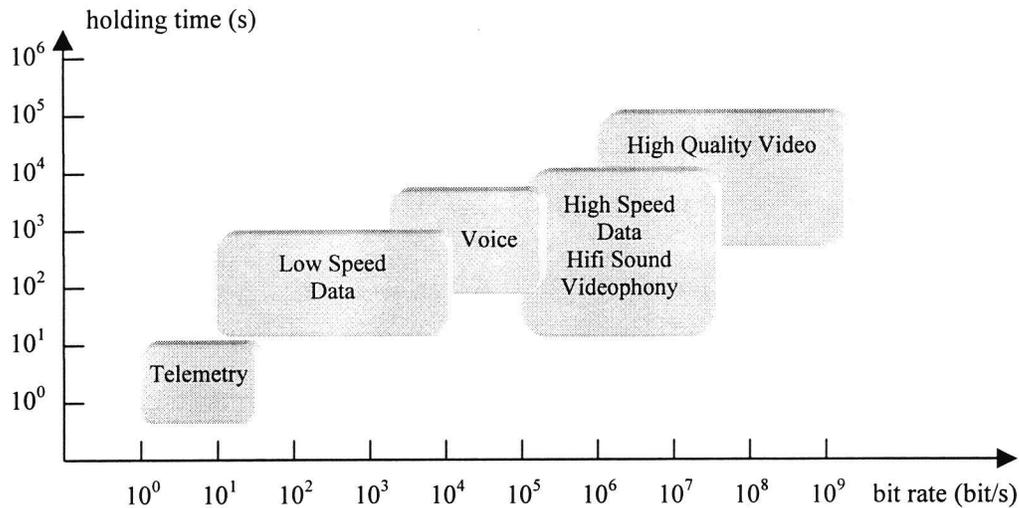


Figure 7 – Range of Services in a Multimedia Network [3]

Ethernet and Token Ring technologies are limited in their bandwidth and capabilities of ensuring timely delivery of multimedia data. Recently, switched Ethernet has become a cost-effective approach to increase the available bandwidth from a station to a server. In a switched Ethernet based network, every station has a dedicated bandwidth of 10 Mb/s to the switch, which has a bigger data pipe to the server with 100 Mb/s bandwidth. The 100 Mb/s Ethernet link from the server to the switch is called fast Ethernet. Although data throughput is increased in the switched Ethernet, the inherent limitations of Ethernet still remain in area of time transparencies. For instance, when an MPEG2 video stream at 4 to 8 Mb/s is requested from a client, and at the same time a CAD file gets transmitted from the server to another client, there is no guarantee that the video stream will be delivered uninterrupted. Most likely jitters will occur to the video stream at the client station. In reality, there could be many data transmissions underway at a particular point of time in the network. Apparently, even switched Ethernet is not a good solution to the problem of providing guaranteed bandwidth for the MMHIS system or any types of distributed multimedia services with a high video quality requirement.

In the last decade, tremendous research has been conducted by both telecommunication and computer network industries in the area of providing high quality data service with guaranteed bandwidth in computer networks. A technology called Asynchronous Transfer Mode (ATM) has emerged as the dominant approach to solve wide and local area data transmission problems by providing very high speed connections with guaranteed bandwidth for various types of services, including the bandwidth hungry video/audio transmissions.

Asynchronous Transfer Mode (ATM) and Gigabit Ethernet

ATM is an extremely fast, high bandwidth, packet-switching technology created by the telecommunication industry. In an ATM environment, computers are connected through adapter cards and network wire to a central ATM switch. ATM breaks all traffic (voice, video or data) into equal sized 53-byte short packets, known as cells. Each cell

has a 5-byte header. Therefore, the user data in each cell amounts to 48 bytes or 90% of the total data. The size of 48-byte information field in the ATM cell was determined through compromise by the two industry groups in Europe and the US, which preferred a 32-byte size cell and 64-byte size cell respectively. In return for the 10% overhead, ATM brings two benefits. First, its short, fixed length cell makes ATM better than frame relay and existing LAN protocols, which all use variable length packets, for carrying real-time data and multimedia applications. Second, ATM's short packet format enables the cells to be formed and routed almost entirely in hardware. This hardware capability is likely to allow far faster network speeds than are possible with today's multiprotocol routers, which rely on software to handle the bulk of the switching task. More importantly, ATM's speed is scalable up to many gigabits/s [2]. The resulting bandwidth is available from each station to a server or another station, which provides a big advantage over the shared bandwidth technology in Token Ring, Ethernet and FDDI. "Asynchronous" in ATM comes from the fact that cells headed to a destination appear at varying intervals. Therefore, it is allowed to perform asynchronous operations between the sender clock and the receiver clock. The difference between the clocks can be solved by using empty cells that do not contain useful information.

When an ATM connection is established, the sender's information is segmented into 53-byte cells and transmitted through the network. The receiver then reassembles the cells into the original format. The 5-byte header carries information about the Virtual Channel (VC) and Virtual Path (VP) in use, the payload type, and prioritizes cell loss. A VP is a group of VCs. The channels and paths are referred to as virtual because many channels and paths can be established simultaneously in the network. A VC carries information of application specific services. The VP aggregates VCs destined to the same destination to properly allocate transmission resources. The flexibility and reliability of the network can be improved by dynamically modifying VP/VC capacity and routing.

The ATM Adaptation Layer (AAL) inserts payload data into the 48-byte information field of the ATM cell. The AAL provides the flexibility to carry different types of services with the same format. The network's task is to use the information in the packet's header to route the cell from one point to another. With some AAL types, up to four bytes of the payload type may be used by the adaptation process itself, leaving 44 bytes for the user data.

ATM Performance Characteristics

Neither error protection or flow control is provided on a link by link basis in an ATM network. The links in ATM networks have a very high quality, or low Bit Error Rate (BER). The omission of error correction protocol improves data transmission efficiency. In addition, ATM operates in a connection-oriented mode, which allows the network to guarantee a minimal cell loss ratio, and therefore provide maximum quality. As a result, the flow control that is used frequently in other computer networks is not needed for ATM. At call set-up, if enough resources in the network are available, the connection is then initialized. When the connection is established, the probability of overflowing the network is very small, less than 10^{-8} [3].

Delay issues in time transparency are mainly applicable to real time services such as the MMHIS. Other computer data transmissions are not particularly sensitive to delays, such as CAD file transmission. In addition, due to the lack of error correction protocols in ATM, three sources of error determine the overall BER in an ATM network: (1) error in the information field in the ATM cell, (2) error in the header field in the ATM cell and, (3) queuing overflow resulting in loss of cell in the switch.

In a Local Area Network (LAN) based ATM environment, the delay times include (1) the distance dependent Transmission Delay (TD), (2) Packetization Delay (PD) at the sender end, (3) Depacketization Delay (DD) at the receiver end, and (4) Switching Delay (SD). The size of ATM cell affects the overall network delay, the transmission efficiency, and the implementation complexity. It is shown [3] that when the size of the ATM cell (packet) is fixed to 53 bytes, the total delay is limited, which is an advantage for real time services.

Quality of Service (QOS)

Properly implemented ATM networks solve the major problems of existing popular networks in the two areas of high speed interfaces and multimedia support with video, voice, and data in one transfer. Constant Bit Rate (CBR) and Variable Bit Rate (VBR) are typically for the transmission of voice and video respectively. Unspecified Bit Rate (UBR) and Available Bit Rate (ABR) can be used for regular data traffic. Each traffic type requires a different quality of service (QOS) with properties such as the amount of bandwidth reserved, delay tolerance, and variation.

QOS of a connection is a general indicator relating to cell loss, delay, and delay variation incurred by the cells belonging to that connection in an ATM network. It represents user perception of service quality at the receiving end of the network. It is a function of terminal capability (bit rate) and network performance such as cell-loss ratio and bit errors in a cell payload [4]. The bit rate ranges from videophone at a very low rate of 64 Kb/s (Kilobits per second) to High Definition Television at over 20 Mb/s. The bandwidth management, key to the support of multiple services on ATM, guarantees QOS for high priority, delay sensitive CBR and VBR traffic, while providing bursty UBR and ABR traffic with fair access to the remaining network bandwidth. For example, ATM switching ensures the integrity of CBR and VBR connections through connection admission control algorithms. Flow control and intelligent buffering are used in the ATM switch to optimize the bandwidth available for data traffic (UBR and ABR). Flow control detects congestion in the network and informs the sending device to slow down.

Gigabit Local Area Networking for MMHIS

In an MMHIS, a number of computers connected through a network medium are used to transmit and receive high quality video streams and regular engineering databases. The MMHIS needs to be scalable to accommodate the data rate of future digital television standards. For instance, one uncompressed High Definition Television (HDTV) stream carries a data rate of over one Gb/s (gigabit per second). The compression ratio for an HDTV signal can be from 20:1 to 50:1. Based on a study by Kinoshita et al. [5], the peak rate can be 65Mb/s and an average 10 to 20 Mb/s for one

HDTV stream transmission in an ATM network. Based on communications with a State Highway Agency (SHA), the possible number of simultaneous users accessing video and data streams can be as high as 50. Therefore, the aggregated data rate in an MMHIS network will well exceed one Gb/s when HDTV level video streams are used.

A gigabit LAN is a LAN for which the physical communication medium has a peak bandwidth on the order of one Gb/s or higher, and for which an end user is able to realize this gigabit performance [6]. Clearly, an MMHIS based network will be a gigabit LAN. In high speed networks, the specification for transmission protocols follows the SONET (Synchronous Optical Network) standards based on the base signal rate of 51.84 Mb/s, which is commonly referred to as OC-1. The higher speeds are OC-3, OC-12, OC-24, and OC-48 with the speeds of 155.52 Mb/s, 622 Mb/s, 1.244 Gb/s and 2.488 Gb/s respectively. ATM adapter cards at OC-3 speed are widely available. Many LAN based ATM switches have aggregated data rate at or over the OC-48 specification.

The Video and Storage Server

Transmission of multiple digital video streams requires very high consistent data throughput for every sub-system in the MMHIS that processes the streams. The sub-systems include the desktop CPU's, bus and display cards, the networking devices (adapters and switch), and the video server and storage mediums. Special attention needs to be focused on the capabilities of the video server and the video storage. For example, a traditional uniprocessor based server is not able to handle multiple video streams. Virtually all video servers are based on the powerful symmetrical multiprocessing structure with multiple microprocessors. Multimedia also requires huge amounts of data storage and a very high sustained data rate. Storage size and sustainable speed are two critical factors for the implementation of a storage server for the MMHIS.

Issues Related to Multimedia Oriented Network Operating Systems

In a multimedia application, it is required that large blocks of digital video/audio data be transferred simultaneously and continuously in order to ensure the high degree of consistency in picture frame and synchronization with audio or other data. The dominant network operating systems used today do not have the capability to coordinate video data flow sufficiently to ensure video quality on the clients' desktops. The current network management software emphasizes data integrity through error control protocols. Therefore, it is imperative to ensure that video/audio data streams flow at consistent latency in the network and no traffic clogs for video/audio data occur. It should be noted that even though many ATM standards have been set, some important standards regarding QOS and MPEG2 video transmission are not ready yet.

Protocols are software layers in the network, which ensure that data arrives without errors, and traffic flows are regulated properly. For video/audio data, a special video protocol is necessary to make sure there is a highly reliable connection for an uninterrupted stream of data. The flow of regular data can be conducted through the normal protocols. With this parallel protocol approach, video/audio data will have priority over other data flows. Normal data flows yield right of way to video/audio data. The challenge in developing a continuous-media software solution for video lies in the

management of a large number of data streams leaving the server. A critical technique in developing such a solution is through the use of a set of ATM specific Application Programming Interfaces (APIs). The new WinSock 2 specification that includes ATM APIs as standard features will be used in the development of the MMHIS.

Requirements for the Multimedia Storage Server

The MMHIS consists of client stations, one or more storage systems, a high-speed ATM network, real-time-service oriented operating systems and customized applications. The client stations are able to receive very fast ATM cells, repacketize them, and decode the video data and display the motion video to the computer screen with synchronized engineering data sets. The storage system should be able to simultaneously process multiple requests for video and data streams and send the requested data fast enough to the clients through the ATM network.

There are four fundamental characteristics of the storage server for MMHIS:

- *Real-time storage and retrieval of continuous video media.*
- *Large data transfer rate and huge storage space requirement.*
- *Dynamic synchronization with and display of traditional engineering data sets with the video frames.*
- *Multiple simultaneous accesses to the video and data files.*

The storage requirement of video footage at MPEG2 quality (average 5 Mb/s) is about 222 GB for a 5,000-lane-mile interstate system when the video is recorded at the speed of 50 miles per hour. This huge storage needs to be randomly accessed by multiple users at any point of the video footage.

Continuous playback of a video stream consists of a sequence of retrieving video blocks from server disks with scheduled play time. It is possible to fetch the video stream from the server fast enough to be played back at the client station. However, the bursty nature of data retrieval from disks does not guarantee continuous operation of the video display. Quite possibly, there will be disruptions of the display due to inadequate video data. Therefore, a buffer storage needs to be used at the client station or the server to contain the video stream before it is played as shown in Figure 8. Buffering is both expensive and time-consuming. The goal is to design a system that would prevent client starvation for video data and at the same time minimizing buffer space and initialization latency. Employing modest amount of buffering enables conventional file and operating systems to support continuous storage and retrieval of isolated video streams.

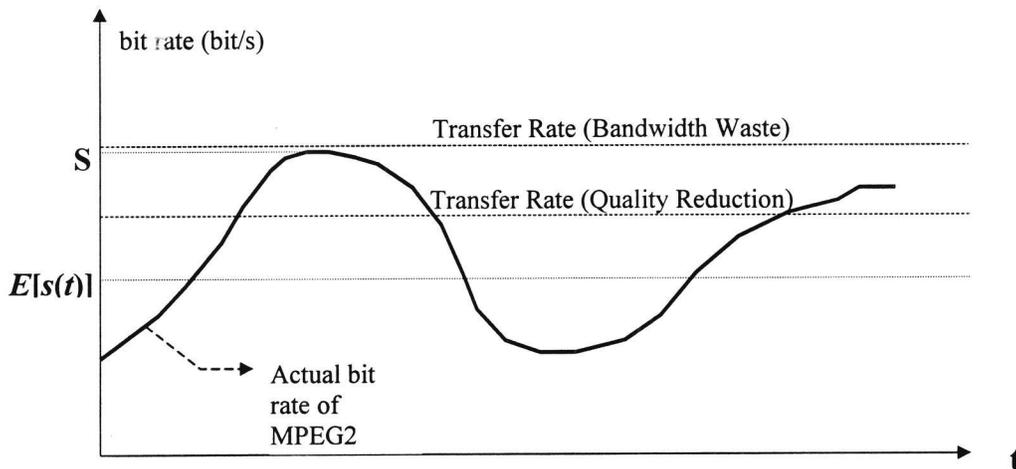


Figure 8 – Buffering Scheme for Video Stream Playback

The multimedia storage server has to process requests from several clients simultaneously. More often than not, different clients may request to view different locations of the highway video footage.

File System for the Server

The following factors need to be considered for the server storage:

- *simple, hierarchical directory structure,*
- *efficient use of low-cost, high capacity disk drives,*
- *efficient handling of both large and small file system objects, and*
- *optimization for random access, rather than sequential access.*

In addition, it is not necessary nor possible to optimize access based on a drive's physical geometry. It is not possible to even determine the real drive geometry at all: track and sector sparing, automatic sector reassignment, etc. The actual disk layout is completely hidden from the user and optimized for large sequential accesses. Most new drives have large data buffers and perform read-ahead and write-behind operations. The best way to get optimum performance is to stream large amounts of sequential data similar to a traditional tape drive. Therefore, the filing system for the video server should be able to:

- *lay the disk out so that objects are in large, sequential chunks,*
- *allocate I/O buffers so that transactions are as large as possible, and*
- *minimize the amount of disk seeking.*

The algorithm to be used is straightforward, assuming all new files are going to be large, and disk space can then be reserved accordingly. Therefore, when allocating space for a file, reserve a large contiguous chunk at the beginning, and then use up the

reservation as needed. As a video file grows, extra contiguous chunks are reserved. When the file is closed, the unused space is freed. In MMHIS, one large video file can be used to cover a few hundreds of miles of roadway. This file may need to be updated only annually. Therefore, this filing system is applicable for MMHIS. In addition, only read operations are allowed on video files in an MMHIS system, which simplifies the optimization of the file structure due to the infrequent write operations. Although this algorithm may cause the fragmentation of disk space, as the contiguous files are very large with the sizes of multiple gigabytes, the side effect of spare blocks can be minimized through an efficient managing algorithm.

In the task of optimization for sequential access, it is realized that in an MMHIS system, the accesses to video files are read-only operations and sequential in nature. However, the initialization of viewing request is random in nature. For instance, multiple users may request to view any section of the roadway at the same time.

It should be noted that cache strategies used frequently to improve storage performance do not apply to video files. Video files used in MMHIS are gigabytes in size. The application of a cache can only add overhead to a disk streaming operation, and the size of any type of cache is much smaller than a typical video file in MMHIS.

Disk Arrays for the Server Storage

The sustained bandwidth of a single hard drive can be as high as 10 MB/s for sequential access. However, when multiple users access the video file(s) in a single drive, the available bandwidth for individual user's video stream is much less than the average theoretical rate, for example, 10 MB/s divided by the number of users. The overhead is due to head seeking time and disk management. Therefore, the structure of putting a number of drives to a Small Computer System Interface (SCSI) channel will not be able to adequately serve multiple users.

A technology called Redundant Arrays of Inexpensive Disks (RAID) is widely used to overcome the inherent throughput limitations of a single disk drive. Various RAID configurations are designed to address either performance or reliability. RAID comes in several flavors from levels zero through five. Each level is optimized for various capabilities, including improved performance of read and write operations, and improved data availability through redundant copies or parity checking.

The computer industry's experience with SCSI has brought to light the need for improvements of versatility and throughput. For instance, even in a RAID and SCSI-2 based system, the storage's maximum sustainable rate is about 20 Mb/s. New applications, like video and image processing, have created a demand for huge increases in storage capacity. Some capacity requirements are so large that it is difficult to configure enough SCSI buses to make sufficient drive addresses available to attach the needed number of drives.

One solution is a relatively new technology called Fiber Channel, which is a standard interface adopted by the American National Standards Institute. The existing implementation of Fiber Channel is called Fiber Channel - Arbitrated Loop (FC-AL).

FC-AL is used as a direct disk attachment interface for I/O performance-intensive systems. SCSI-3 (Small Computer Systems Interface-3) has been defined as the disk protocol, which is also technically referred to as the SCSI-FCP.

The Fiber Channel interface is a loop architecture as opposed to being a bus - like standard SCSI-2. The Fiber Channel loop can have any combination of hosts and discs up to a maximum of 126 devices and provide 100 MB/s of bandwidth. The maximum cable distance can be as long as 10 kilometers. In addition, FC is a generic, standard interface, supporting many protocols, such as SCSI, Internet Protocol, and ATM. The loop structure enables the rapid exchange of data from device to device. Devices can be removed or inserted without disrupting the operation of the loop. The drives attach directly to the backplane for both signal and power. Neither jumpers nor switches need be set on the drive. The controller determines a drive's address from either the relative position on the backplane or the drives unique IEEE Fiber Channel address.

MMHIS Development

The test data for the MMHIS was collected in a van as shown in Figure 9, which uses Super-VHS or a similar quality system for video recording. The source video is then sent to the compression system for MPEG encoding. Figure 9 also illustrates the multimedia data flow within a state highway department. ATM networking technology is used in MMHIS to link the client stations, the production station, the server and the encoding system.

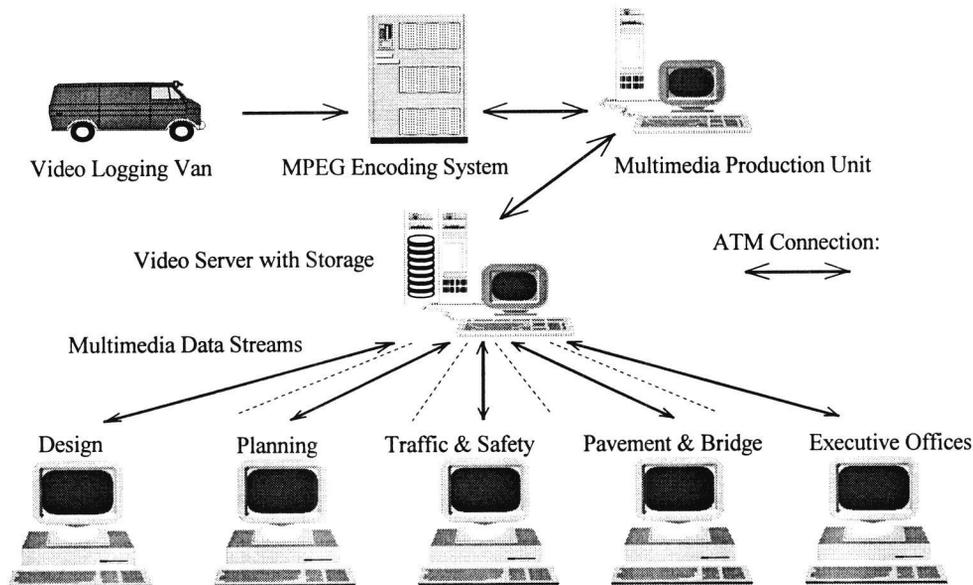


Figure 9 – Video Data Flow In The MMHIS For A State Highway Department

A motion JPEG comparable video stream in MPEG format is normally referred to as a type of high quality MPEG specification known as MPEG2 of Main Profile at Main Level. A combination of profile and level determines the frame rate and size. For example, MPEG2 of Main Profile at High Level Type 1 is to be used for US HDTV with the resolution of 1,152 lines/frame, 1920 pixels/line and 30 frames per second [7]. The

current mainstream MPEG2 is Main Profile at Main Level with the resolution of 720 by 480. It is determined that in order to provide useful video information for highway engineering work, high quality digital video for the MMHIS is required. Either MPEG2 or Motion JPEG can provide Super-VHS or higher quality that meets the quality requirement. Even though motion JPEG based CODEC's provide very high quality video, it requires over 5 times more data throughput than a comparable quality MPEG video stream. Therefore, MPEG2 of Main Profile at Main Level is to be used in the actual development of the MMHIS.

The Hardware Structure for the MMHIS

- Client and Server.

Based on current practices of highway agencies and fast growing capabilities of Intel x86 processors and related I/O sub-systems, the hardware platforms for both the video server and clients are going to be Pentium or better computers. The video server is symmetrically based with four or more state-of-the-art Intel processors to distribute the management of data streams among processors. The computer bus is based on PCI with a peak I/O bandwidth of 132 MB/s.

- Storage.

The storage requirement of video footage at MPEG2 quality (average 5 Mb/s) is about 222 GB for a typical 5,000-lane-mile interstate system when the video is recorded at the speed of 50 miles per hour. The sustained throughput for the video storage is one of the critical elements in the MMHIS to ensure timely delivery of multiple video streams to the desktop computers. Fiber Channel and RAID-3 will be used as the server storage technology.

- ATM based networking devices.

This includes adapter cards for each computer and switch(es). OC-3 based 155Mb/s cards and a 2.5Gb/s ATM switch are used in the development.

- MPEG2 encoder

One MPEG2 encoder of Main Profile at Main Level is necessary for development. Only one encoder is needed for a production level MMHIS. An MPEG2 decoder and video card is used for each client station. Many vendors have developed combo PCI based video cards that overlay MPEG quality motion video on the computer screen. New MPEG2 based combo video cards will be used in this MMHIS, which allow us to overlay MPEG2 video on the computer screen of a client station.

OPERATION OF MMHIS

Starting up the System

MMHIS is started by double-clicking the icon of the MMHISMain.EXE file. The opening screen is similar to the screen shown in Figure 10.

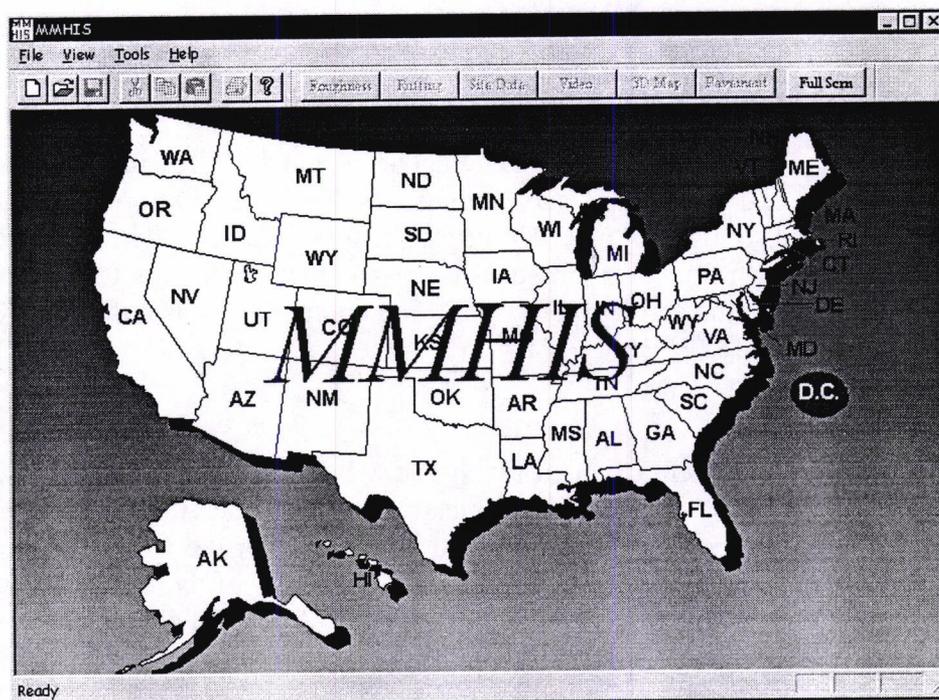


Figure 10 – Startup Screen of MMHIS

Starting a New Query

A main application of the MMHIS is to examine the right-of-way view along with site-accurate location data. The user can start up a query by giving input data on the location of the site: choose *New* from the *File* menu to open the *MMHIS Query Location* dialog box shown in Figure 11.

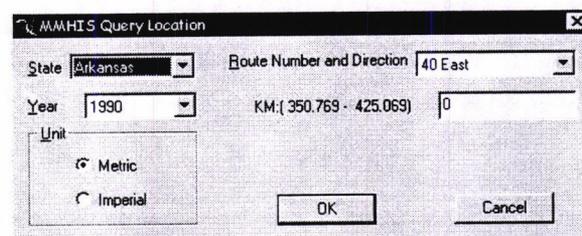


Figure 11 – The Query Location Dialog Box

The user is required to choose state, route number and direction of the highway that is going to be queried, and the year number from the above dialog box. The starting

milepost number needs to be input in the above dialog box. Note that the default unit of the milepost number is kilometer. The unit can be changed to mile by clicking on the button shown in the dialog box. After the above information is entered into the dialog box, click *OK* to begin running the query. Please note that MMHIS dynamically loads database information into the system. For instance, when the route number and direction is selected, the available years in the next list box are displayed immediately. When the year number is chosen, the distance range of the particular highway is immediately shown in the third entry. For more information on how to manipulate a query, see the sub-section *Running a query*.

Opening an Existing Query

Queries can be saved into MMHIS query files. When saving a query, the query state, route number, direction, milepost, unit setting, data update rate, window management settings, windows' layout, site data format, font setting, and graphing window zooming factor are all stored to a disk file. The next time MMHIS is run, the user can simply open the saved query and continue doing work on that query. There are two ways to open an existing query. One is to choose the file from the *Most Recently Used File* list on the *File* menu. The other is to choose *Open* from the *File* menu to activate the *Open* dialog box shown Figure 12.

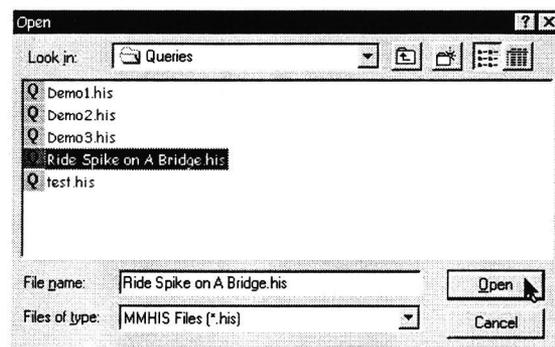


Figure 12 – The File Open Dialog Box

The default extension for the query files is *.HIS* (meaning Highway Information System). To keep every file organized, it is recommended that all query files be put into a common directory, e.g., *C:\MMHIS\QUERY*.

Running a Query

After an existing query is opened or a new query is started, the system is ready to run the query. The application window will look similar to the one shown in Figure 13.

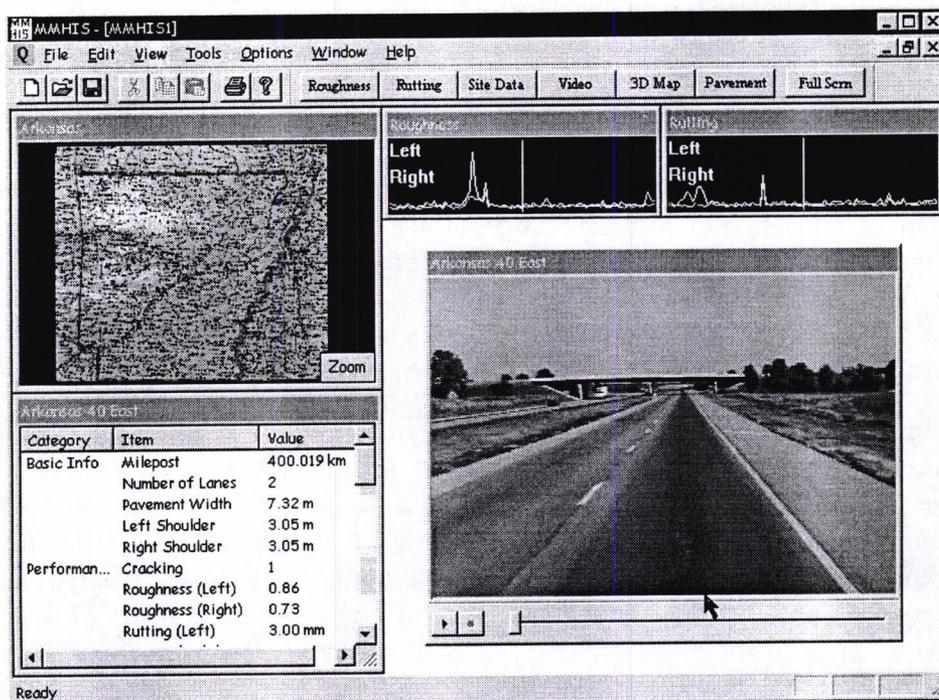


Figure 13 – An Open Query in MMHIS

The highway video is shown at the bottom-right corner of the frame window while the corresponding site data are shown at the bottom-left corner of the window. Two graphing windows are shown at the top-right corner of the frame window. This will be further explained in the sub-section *Dynamic Graphing*. The 3D-map window is shown at the top-left corner of the frame window. The following operations can be conducted on the query.

- Running the video

The button with a small arrow on it on the bottom-left corner of the video window can be used to play and stop the video. While the video is playing, data in the site data window will change accordingly. The video's play speed, the video window's size, and many other factors can also be configured through a context menu offered by the video window.

- Dragging the video to a new location of the highway

This can be achieved by using the mouse to drag the little slider on the slider bar on the bottom of the video window.

- Specifying a new location

A new location can be specified by choosing *Specify Location* from the *Tools* menu. The sub-routine that this menu item activates is the same one used to make a new query. It is shown in Figure 11.

- Changing the font for the site data window

This is achieved by choosing *Choose Font...* from the *Options* menu. The dialog box shown in Figure 14, which is activated by the above menu item, allows users to choose a new font. Note that a context menu is also offered to the site data window. The *Choose Font...* option is also on the context menu.

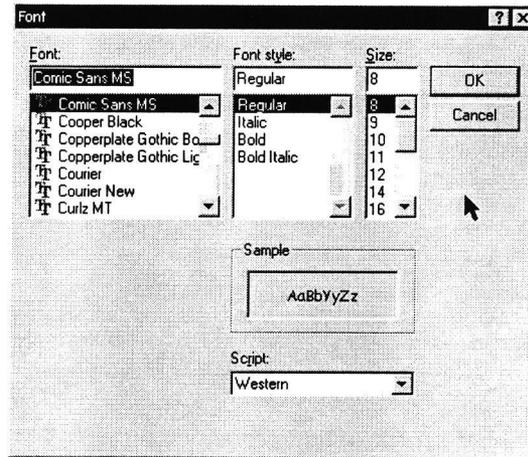


Figure 14 – Font Selection Dialog Box

- Changing the unit for the site data display

The unit used in the site data display in a new query defaults to the Metrics system. It can be changed by choosing *Units* from the *Options* menu. This is shown in Figure 15.

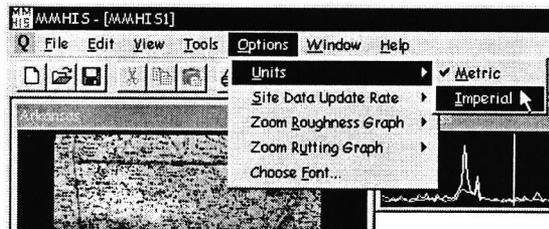


Figure 15 – Changing the Unit Through Menu Selection

- Changing the data update rate for site data table.

The fastest data update rate is every 25 meters. The actual displaying rate and quality of video motion is limited by the machine speed and the distance spacing among adjacent records in the database. Currently the AHTD database contains records for every 25 meters. To change the data update rate, choose *Site Data Update Rate* from the *Options* menu, as shown Figure 16. The option is also offered in the context menu.

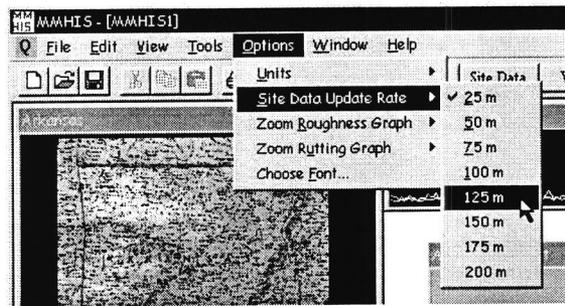


Figure 16 – Changing the Site Data Update Rate

- Opening another query

The current hardware speed does not allow the system to run more than one query (open multiple video/site-data-table) simultaneously at a good quality level. However, the user can still open multiple video windows simultaneously. Windows of each query can be resized and re-positioned so that they can be seen simultaneously on the screen. The system allows the running of one query's video while all the other queries' videos are frozen (i.e. the videos are paused). This is shown in Figure 17.

- Making turns

The system allows users to choose which way to proceed at intersections or exit ramps. When the vehicle approaches an intersection or an exit ramp, the highway video pauses and MMHIS displays arrows to show possible turning movements, as shown in Figure 18. Users can click on one of the arrows to make turns. If none of the arrows is clicked for a certain time (configurable by the user), the system will take the default option (normally the *Through* allow) and continue to play the video.

- Change the site data display format

The site data display format can be changed through the context menu for the site data window. Two formats are offered for the display. One is called categorized format, which is the default. This format shows the site data grouped by categories. The groups can be expanded and collapsed by double clicking on the category name. When a group is collapsed, it is shown in a single line with *<Closed>* as the item name. Shown in Figure 19 is the case with "Layer Info" and "Other Info" groups closed.

The second format is user configurable, where only two columns are shown in the site data window, shown in Figure 20. The user can configure data items and the order of the items to be displayed through the use of a dialog box, shown in Figure 21. In the dialog box, items in the left list box represents those shown in the site data window. Available items are listed in the right list box. An item in one list box can be moved to the other list box by double clicking on it. Items in the list boxes can also be selected first and then moved to the other list box by pushing one of the buttons in the middle of the dialog box. The order of the items in the left list box can be changed with the two buttons at the left of the list box. Default settings can be restored with the *Default* button.

The dialog box shown in Figure 21 is invoked by using the site data window context menu.

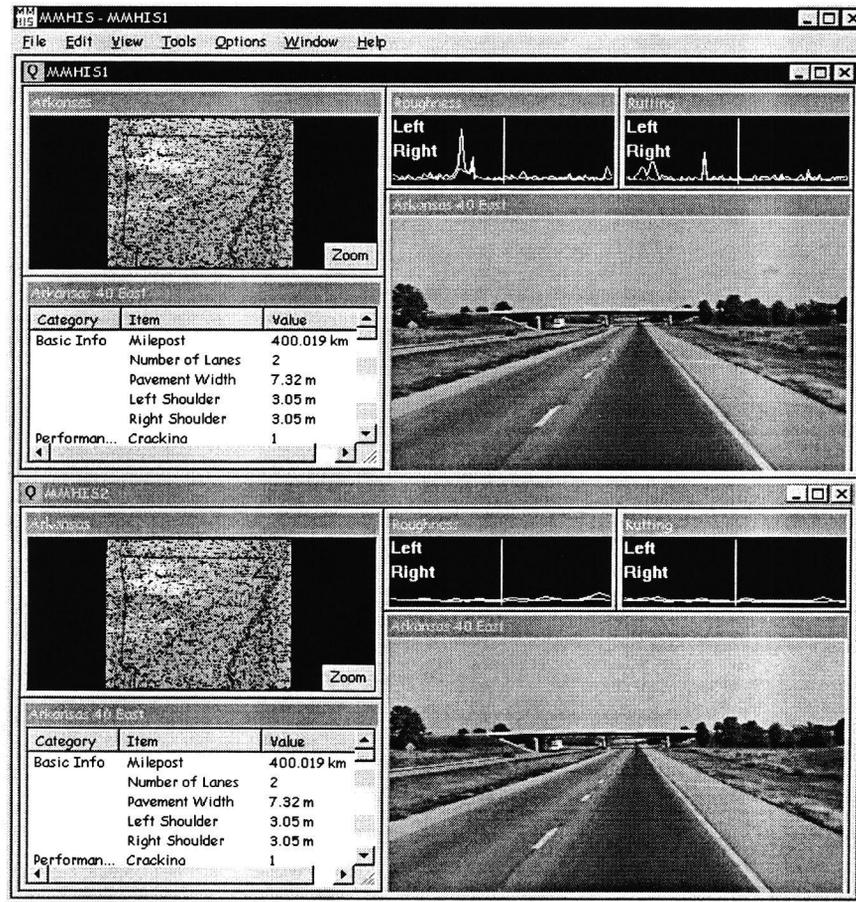


Figure 17 – Two Queries

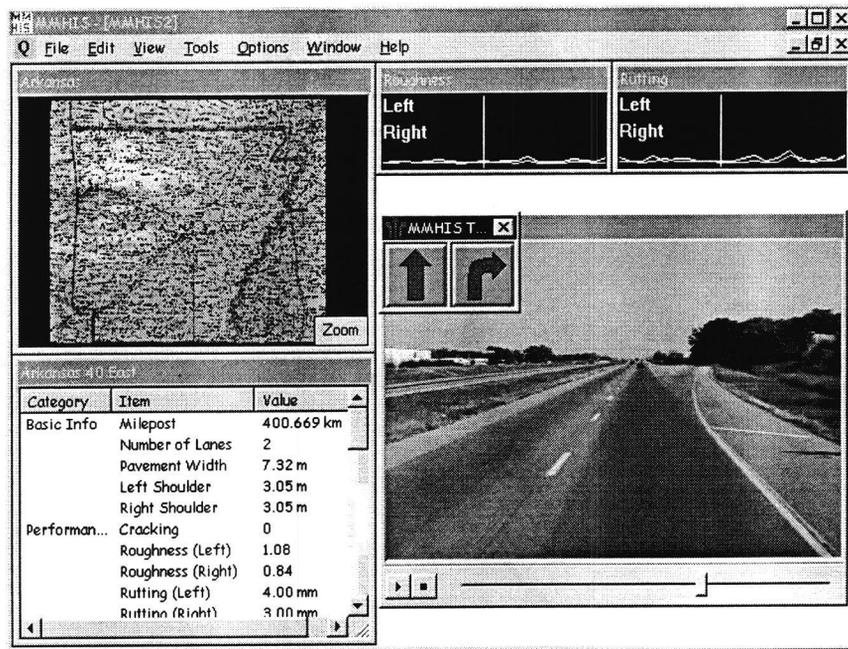


Figure 18 – Making Turns

Category	Item	Value	
Basic Info	Milepost	400.019 km	
	Number of Lanes	2	
	Pavement Width	7.32 m	
	Left Shoulder	3.05 m	
Performan...	Right Shoulder	3.05 m	
	Cracking	1	
	Roughness (Left)	0.86	
	Roughness (Right)	0.73	
	Rutting (Left)	3.00 mm	
	Rutting (Right)	3.00 mm	
	Patching	99	
	Flushing	3.00	
	Constructi...	Structure Number	2.20
		Rate	22.10
Fiscal Year		0	
Year		85	
Layer Info	Project	IR 40-1-56	
	<Closed>		
Traffic In...	ADT	11638	
	ADL	3079	
	Growth Factor	6.20	
	ADT	11638	
Other Info	<Closed>		

Figure 19 – Categorized Site Data Format

Item	Value
Milepost	400.019 km
Number of Lanes	2
Pavement Width	7.32 m
Left Shoulder	3.05 m
Right Shoulder	3.05 m
Cracking	1
Roughness (Left)	0.86
Roughness (Right)	0.73
Rutting (Left)	3.00 mm
Rutting (Right)	3.00 mm
Patching	99
Flushing	3.00
Structure Number	2.20
Rate	22.10
Fiscal Year	0
Year	85
Project	IR 40- 1- 56
Layer 1 Material	RE
Layer 1 Thickness	0.06 m
Layer 2 Material	AC
Layer 2 Thickness	0.08 m
Layer 3 Material	FC
Layer 3 Thickness	0.01 m
Layer 4 Material	

Figure 20 – User-defined Site Data Format

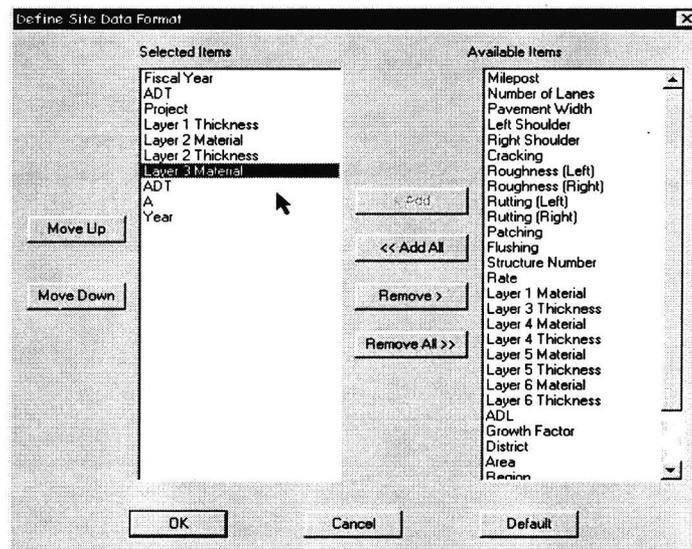


Figure 21 – Dialog Box Used to Define Site Data Format

- Saving a query

To save the query that is currently running, choose *Save* from the *File* menu. For new queries, this will bring up the *Save As* dialog box which asks the user to give a name and location for the query to be saved. For existing queries, the system will save the query without giving user the opportunity to change the name of the query. To save the query using a different name, choose *Save As...* from the *File* menu. The same dialog box that is mentioned above will show up, as shown in Figure 22. Refer to the section *Open an existing query* for more details about what is saved for a query.

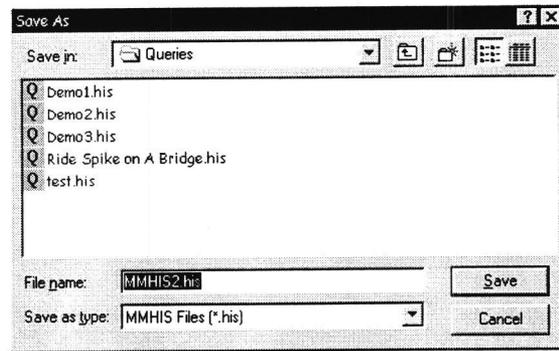


Figure 22 – The Save As Dialog

Dynamic Graphing

An additional capability of dynamic graphing is built into the MMHIS. The data sets shown in the table by the side of the video do not present relative information on the whole section of road. This dynamic graphing capability allows the user to view the values of various attributes, such as roughness and rutting at this particular location against all the values in the road section. The real-time location as the video indicates is shown with a vertical bar on the curves. The ranges that the graph windows show can be set by choosing *Zoom Roughness Graph* and *Zoom Rutting Graph* from the *Options* menu. This is shown in Figure 23.

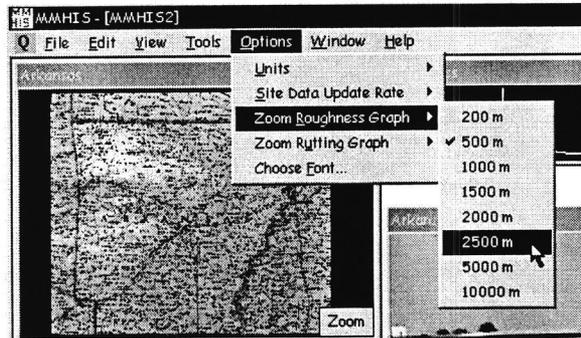


Figure 23 – Changing the Zooming Range for the Graphs

The vertical bar in the graphing window shows the current vehicle location. It can be dragged to a new location. This is shown in Figure 24.

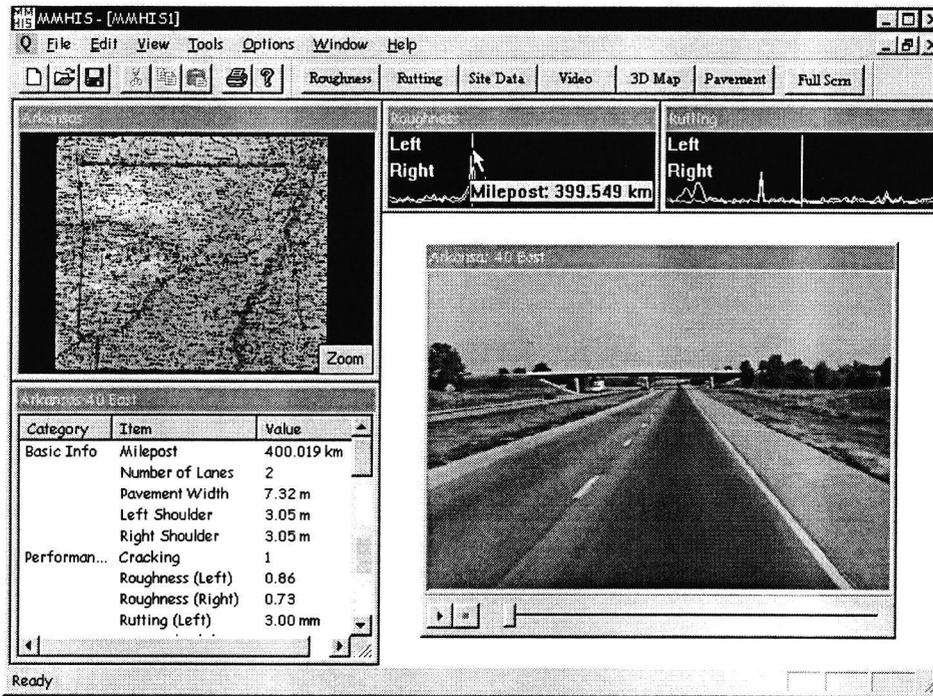


Figure 24 – The Draggable Vertical Bar in Graphing Windows

Using the map

The map interface offers a convenient method to query data through clicking the right mouse button on a point on the map. A small pop-up window will show up with the coordinate information of the point. The road information, if any, will be displayed. Upon the selection of a menu item, the video will go to that location, while the site data display will be updated to reflect the new location information, shown in Figure 25.

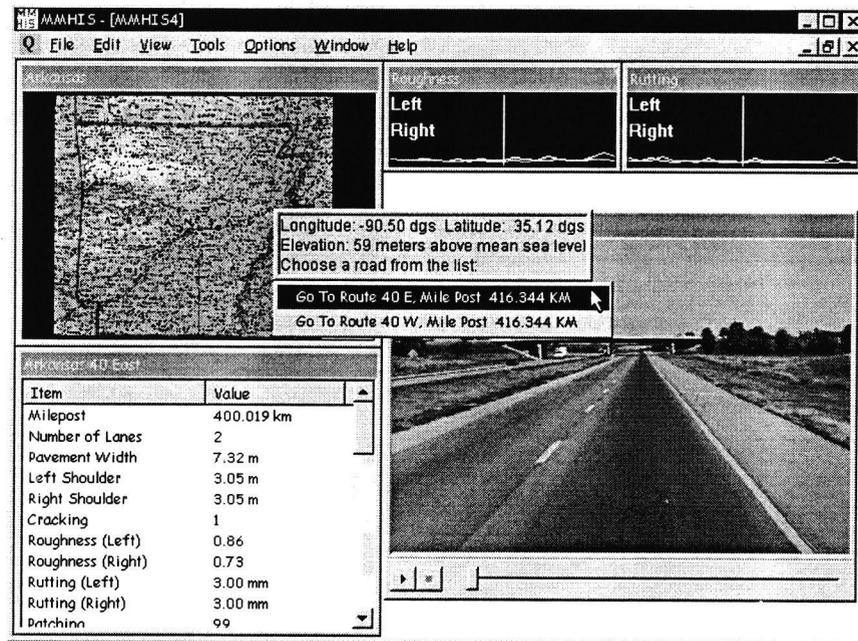


Figure 25 – Getting Information from the Map

Zooming and panning operations are offered in the map window. There are two ways to conduct zooming operations. The first is to conduct a zooming operation directly on the map through clicking the center point of the area and dragging the mouse to define the zooming area, shown in Figure 26.

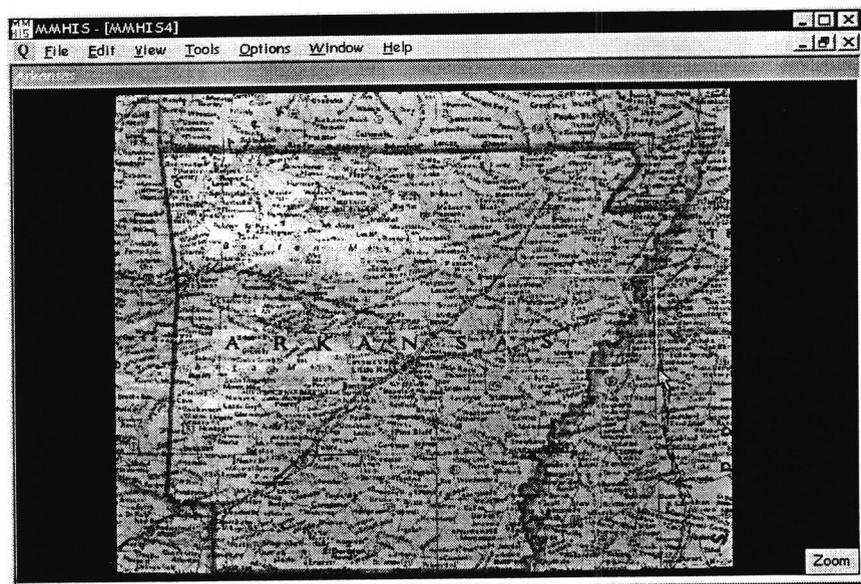


Figure 26 – Directly Zooming on the Map

The second way is to open the zooming window at the corner of the map window and zoom through that window. To open the zooming window, simply click on the *Zoom* button. A resizable rectangle is in the window illustrating the current zooming area. In addition, two slider bars are offered in this window so that the user can use them to adjust the viewing angles. The user can zoom and pan to a specific area by resizing the rectangle and moving it to the destination. When the *zoom* button at the bottom of the zooming window is clicked, the map is updated. An example is shown in Figure 27. The small circle on the road shows the current vehicle location.

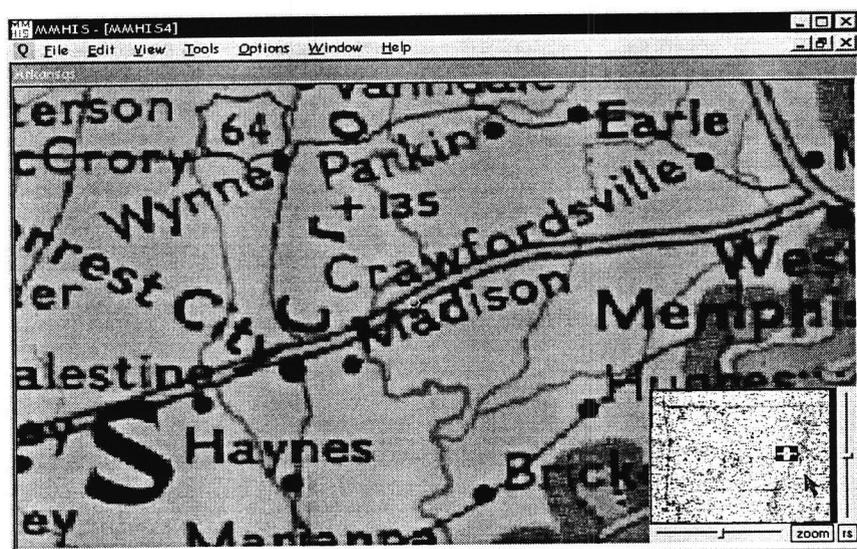


Figure 27 – A Zoomed-in Map with an Open Zooming Window

Building the video frame index

The index building interface is used to build frame indices for the video. With this interface, users first open a video file by specifying the video file name or by browsing the video files from the disk. The global ranges can be specified with the controls in the window. In particular, the start and end frame numbers can be either manually set, or by moving the slider in the video window to the frame and set the frame numbers using the buttons in the window. The state, route number and direction, start and end milepost, and unit can also be chosen. The index-building module uses the vehicle speed data in the database to calculate the frame index. If the speed data in the database is accurate, the above information is enough to calculate the frame index for the whole video. If the speed data is not quite accurate, key points can be used to increase the accuracy of the calculation. In addition, turning points and turning prompts must be set manually because there is no data in the database showing the turning information. Users define key points by moving the video to a specific frame and by specifying the key milepost for that frame. Several search buttons are offered in the window to help the user find the already defined first key point, previous key point, next key point, last key point, previous turning point, and next turning point. Key points can be added or removed by clicking the *Add Key Point* or *Remove Key Point* button. For a frame at an intersection or an exit ramp, a turning point is defined by checking the left turn, through, and/or right turn check boxes and specifying the destination state, route number and direction, and milepost. An option is offered to allow the video frames in the video window to be synchronized with the key mileposts displayed in the window. When this option is checked and the already defined key points and turning points are being searched, the video frame display in the video window is synchronized with the key points. The database is updated after the *Update Database* button is clicked by the user. The index building interface is shown in Figure 28.

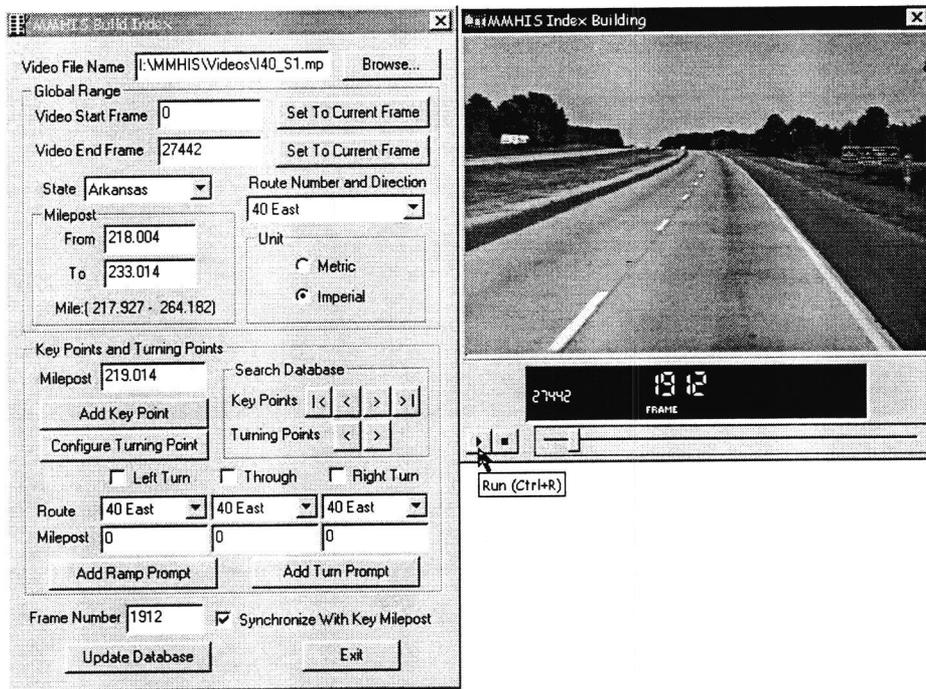


Figure 28 – The Index Building Interface

CONCLUSION

To implement the MMHIS in an operational environment, a high performance network and a powerful video and storage server is necessary. In order to have simultaneous and instant accesses to the MMHIS data, the application of new technologies such as ATM or FastEthernet, and RAID is needed. In addition to the installation of a high performance network system in the headquarters in a highway department, the distribution of hard copy videodisks to remote district offices may be a plausible alternative to building a wide area network. For example, the maximum capacity of a new kind of CD, the Digital Versatile Disk (DVD), is 18.8 gigabytes, which can hold 400 lane-miles video information at MPEG2 quality. The implementability of an MMHIS needs to satisfy three factors: (1) maturity of hardware and database technologies, (2) acceptable implementation costs, and (3) high video quality and resolution.

We believe that the technologies associated with the implementation of MMHIS are mature and the costs associated with the implementation are continuing to come down. The cost-effectiveness of using the MMHIS is exhibited not only in the form of improvement of office productivity, but also in the actual cost savings through the reduction of travel for site inspections. Preliminary highway site inspection normally involves two people and can take as much time as two or more days. If the number of such trips can be reduced through the use of the MMHIS, the savings of travel costs and labor in just one year for a highway department can be substantial.

As MMHIS is technology-driven, additional features can be built into MMHIS over time. New features of Geographical Information System and high-resolution 3-D terrain data will be useful for an integrated highway management and design. When statewide terrain data in the MMHIS is updated with Digital Elevation Models (DEM) of sub-meter resolution, it is possible to conduct preliminary engineering design of cut-and-fill and planning the development of new transportation systems.

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DEVELOPMENT OF A PAVEMENT MANAGEMENT SYSTEM

TRC-9606

Final Report, Part Two

Calibration of dTIMS® for Arkansas' Pavement Management System

Submitted to

Arkansas State Highway and Transportation Department

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Project Abstract

The goals of the project were (1) to develop a multimedia based highway information system, and (2) to evaluate the current practice of pavement management at AHTD, make recommendations, and calibrate the application of a pavement management system (PMS) for the state of Arkansas. Part One of the Final Report covers the first area on the development of a Multimedia Based Highway Information System (MMHIS). MMHIS extends the capabilities of current photo logging facilities. Part Two of the Final Report covers the second area on the calibration of an existing PMS software, dTIMS®. The two areas are within the activities of highway engineering and pavement management. However, due to the fact that the technical contents of the two areas do not overlap, the Final Report is divided into two separate parts.

Part Two presents the calibration of dTIMS® for AHTD. Based on data sets collected with the ARAN vehicle, AHTD Technical Services manages IRI, rutting measurements, and other data sets for every section of the National Highway System (NHS). The data collected with the ARAN vehicle is used as input values for the PMS software, dTIMS®. The calibration of dTIMS® focused on the Interstate and NHS (National Highway System) of Arkansas. The following tasks were completed in this research: (1) segmentation of highway sections into homogeneous sections, (2) development of traffic loading history based on Equivalent Single Axle Loads for every homogeneous section of highway, (3) development of necessary performance prediction curves for each type of highway pavement, (4) setting up dTIMS® for optimization analysis, including treatment triggers, treatment reset values, rehabilitation costs, and decision trees, (5) documenting optimization runs for pavement rehabilitation with Arkansas data. The basic framework of a PMS for Arkansas was setup in the research. Further updates as new data are collected is required for the PMS to be useful to the AHTD.

Acknowledgement

The principle investigators are grateful for the support provided by the research staff of AHTD. Specifically, Mr. Alan Meadors, Staff Research Engineer of AHTD, provided technical advice on the dTIMS®'s calibration. Mr. Mark Evans helped provide needed data for dTIMS® and MMHIS. The coordination of the project by Bobby Bradshaw and Jennifer Williams was extremely helpful.

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INTRODUCTION

Current Practices

The Federal Highway Administration defines a Pavement Management System (PMS) as a set of tools or methods that can assist decision-makers in finding cost-effective strategies for providing and maintaining pavements in a serviceable condition (1). The Arkansas Highway and Transportation Department (AHTD) has a pavement management team in place to meet the requirements of Federal mandates. In order to improve the process of pavement management for Arkansas, AHTD initiated a research project to evaluate its existing PMS and calibrate the data analysis of the PMS. This project is the result of an AHTD sponsored effort to improve its PMS.

The Intermodal Surface Transportation Efficiency Act (ISTEA) enacted in 1991 by US Congress strongly recommended state development of a PMS for Federal-aid highways. ISTEA defines a PMS as a systematic process that provides, analyses, and summarizes pavement information for use in selecting and implementing cost-effective pavement construction, rehabilitation, and maintenance programs. As a minimum, the PMS should include:

- Data Collection & Management
- Data Analysis and Feedback
- Data Update

In 1993, the AHTD purchased a highway data collection vehicle, ARAN, from RoadWare Corporation in Canada. ARAN is an acronym for Automatic Road Analyzer. The ARAN vehicle is used to collect data on rut depth and transverse profile, roughness, pavement surface images, and other highway data. Rut depth is measured with ultrasonic sensors mounted across the front of the vehicle on a rut bar. The rut bar can be extended to a length of 12 feet. Roughness is measured using an accelerometer-based response type road roughness measuring system (RTRRMS). Accelerometer-based RTRRMS' measure the response of the vehicle axle to the roughness to the road. ARAN uses the International Roughness Index (IRI in/mi.) as its roughness index.

A video picture is also taken of the road's right-of-way through the windshield, while two shuttered video cameras at the rear of the vehicle take video pictures of the pavement surface. Later in the office, an operator records distress data with a set of special keyboards while reviewing the post-trip video of the pavement surface. Distress data can be recorded for up to 20 types, 3 levels of severity, and 5 levels of extent.

Based on data sets collected with the ARAN vehicle, the AHTD Technical Services Section provided IRI, rutting measurements, and other data sets for every section of the Interstate and National Highway System (NHS). However, manually analyzed distress data (i.e. cracking, faulting) is only available for a portion of the interstate system in the increasing log mile direction. Automated analysis of pavement surface distress is currently not available to AHTD.

Objectives of the Research

Pavement management can be categorized into two levels: Network level and Project level. Project level pavement management is concerned with information for a specific project or location. Therefore, more detailed technical information is required for specific sections or sub-sections of pavement. Network level pavement management is concerned with the network as a whole. In other words, administrative level policies and priorities that affect the entire road network are established. Budgets can be developed to optimize the allocation of maintenance and rehabilitation funding.

In the past, pavement management focused on the project level. However, with the increase in pavement data collection and performance models along with the decreasing costs in computer hardware and software, network level management is also used extensively for rehabilitation programming and research purposes.

The data collected with the ARAN vehicle is used as input values for the PMS software dTIMS® from Deighton Associates Limited, also a Canadian firm. dTIMS® is a PMS analysis software that has been installed at the AHTD for several years. In the summer of 1997, AHTD determined that a new version of dTIMS®, Version 6, fits the future needs of AHTD. As a result, this portion of the project focuses on the calibration of the new version of dTIMS® for interstate highways and other highways in the National Highway System (NHS) of Arkansas, including the following tasks:

- Segmentation of highway sections into homogeneous sections
- Development of traffic loading history based on Equivalent Single Axle Loads (ESAL) for every homogeneous sections of highways
- Development of necessary performance prediction curves for each type of highway pavements
- Setting up dTIMS® for optimization analysis, including treatment triggers, treatment reset values, rehabilitation costs, decision trees
- Documenting optimization runs for pavement rehabilitation with Arkansas data

INTRODUCTION TO dTIMS®

Description (P-Curves, Treatments, Triggers, etc.)

AHTD is planning to implement the new version of the software dTIMS® for use in its Pavement Management System. dTIMS® will assist the AHTD in making funding decisions by finding the optimal set of maintenance and rehabilitation strategies to apply to a network under a set of constraints (2). These constraints could be costs (overall, district), time/ESAL, or number of jobs. dTIMS® predicts the growth or deterioration of performance data over time using performance curves. Performance curves are expressions that represent relationships between performance data fields and some independent variable, such as age, ESAL, or AADT (Average Annual Daily Traffic). The classical example of performance curves is the concept of the pavement serviceability index (PSI) introduced by AASHTO.

PSI is based on a 5-point scale, with 0 being the worst and 5 the best. The PSI value of a pavement will decrease over time until it reaches a level of PSI that is viewed as unacceptable. Figure 1 is an example of a performance curve.

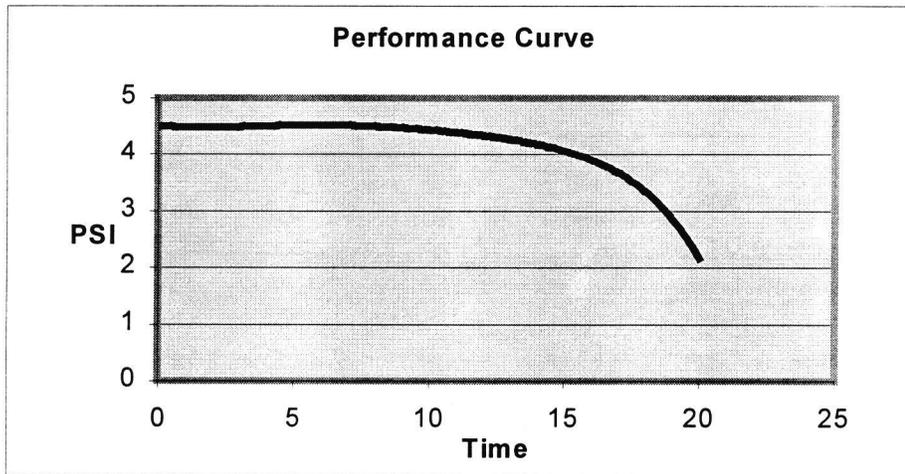


Figure 1 – Example Performance Curve

dTIMS® uses triggers to determine when to apply various treatments to a pavement segment over a given period of time. A treatment could be a rehabilitation (thick overlay), periodic (surface coat), or maintenance treatment (crack sealing). Performance curves, rehabilitation treatments, triggers, and filters are used to analyze the pavement network and generate strategies. dTIMS® develops a list of repair strategies for every analysis set. An analysis set defines the characteristics of the group of elements to be analyzed and allows for multiple budget scenarios within that analysis set. Then, dTIMS® optimizes the network and selects one strategy for each element in the network so that all objectives are met and constraints are satisfied.

Generating Strategies

dTIMS® generates a list of feasible repair strategies for each element, or road segment, and predicts how each strategy would effect the element's condition over the analysis period. The list of feasible strategies represents every reasonable course of action that could be performed on each element during the analysis period. dTIMS® performs the following steps for each element starting at the beginning of the analysis period: (2)

- 1) Calculate the do-nothing strategy for the element for the Analysis Period.
- 2) Calculate the maintenance-and-periodic-only strategy for the element for the analysis period.
- 3) Start at year 0 of the treatment application period
- 4) Increment the current year by one
- 5) Select a treatment.
- 6) Check triggers for the treatment to see if current condition from the maintenance-and-periodic-only treatment is within those limits. If yes, go to step 7. If not, go to step 8.
- 7) Generate a strategy: apply the triggered treatment; reset the condition and other attributes; calculate the future condition; check for other treatments and apply them in the years they are triggered and resetting as appropriate; calculate the costs and benefits for the entire strategy; store the strategy in the list.
- 8) If there are any more treatments, go to step 5.
- 9) If there are any more years in the treatment application period, go to step 4.

Optimization

The purpose of optimization is to select the best strategy for each segment by examining the effects of various repair strategies while staying within the specified budget. dTIMS® allows the user to choose which segments are included in an optimization through a process of selecting an analysis set. dTIMS® uses filters to determine what segments belong to a particular analysis set. The filter defines the characteristics of the segments to be included in the optimization. Each analysis set can contain up to five budget scenarios. The different budget scenarios show how changing an annual budget can effect the condition of the network. Budget scenarios can also be split into budget categories. Budget categories provide the ability to assign portions of an annual budget to different treatments. Optimization will select a repair strategy for each segment that meets an overall condition objective and satisfies constraints. dTIMS® uses the heuristic optimization technique called the Incremental Benefit Cost Technique. It determines the most incremental benefits per dollar invested. The incremental benefit-

cost ratio is defined as the ratio between the increase in benefit to the increase in cost between successive strategies. The heuristic optimization analysis happens after the system calculates the incremental benefit cost for all strategies on all of the segments. The steps in this process are as follows: (2)

- 1) Sort all strategies in descending order of incremental benefit cost regardless of the element they are on.
- 2) Start at the top of the list and check whether there is enough money in the budget in each year to cover the yearly cost of that strategy. If there is, select that strategy for that element.
- 3) Reduce the available budget in the respective category by the annual yearly costs of the treatments for the selected strategy.
- 4) Continue down the list doing the same process for each strategy on this sorted list.
- 5) As the analysis continues, a strategy is replaced by another for the same element, only if the next strategy provides a greater benefit and the budget is available.
- 6) The process is finished when there are no more strategies, or the budget is exhausted.

Construction Program

The strategies selected by optimization form a Construction Program. A Construction Program is a list of all the selected strategies or projects in each year for every segment in an analysis set. Computer optimization cannot consider all of the factors involved in pavement management. Therefore, dTIMS® allows the user to change the selected strategy for a particular segment. The following factors may affect the contents in a Construction Program: (2)

- Political pressure.
- To combine the work on this segment with an adjacent segment to make one construction project.
- To spread the work around a certain geographical area.
- To see the network impacts of various "what-if" scenarios.

CALIBRATION METHODOLOGY

Inventory Database (Segmentation)

The first step in calibrating dTIMS® was to segment the state highway network. The focus of the initial implementation of AHTD's PMS will be federally funded highways, or the National Highway System (NHS). These highway networks include two categories: Interstates and other Non-Interstate NHS highways. Therefore, the highway network to be analyzed with dTIMS® was split into two sub-networks: the Interstate System and the Non-Interstate NHS. The focus of segmentation was to split the network into homogeneous segments. A homogeneous segment has similar basic engineering characteristics throughout the segment. In other words, it is a segment that is considered to be uniform in terms of pavement type, functional classification, traffic, condition, etc. The segmented highway network will form the basis for dTIMS®' inventory file, the most fundamental file required in dTIMS®.

P-Curve Development

The next step in calibrating dTIMS® was to develop performance curves. One of dTIMS®' input requirements for analysis is a performance data field. The growth or deterioration of performance data fields is calculated using performance curves. Condition ratings such as ride quality, structural capacity, IRI, and rutting are the performance data fields for Arkansas' PMS. These condition ratings were plotted vs. the total load on the pavement or cumulative ESAL (Equivalent Single Axle Load) to produce the performance curves. AHTD has two years of available performance or condition measurements for the Interstate system and one year of available data for other NHS highways. This posed a problem for developing performance curves. For each section, a maximum of only two points was available to create a curve, which is impossible. Therefore, in order to develop statistically sound performance curves, all the pavements grouped under one pavement type/classification were considered one pavement group. Since each of the individual pavement sections had its own unique cumulative ESAL and performance measurements, the plots for each pavement group would have enough data points to make a well-defined curve. After each of the performance measurements was plotted vs. the pavement's accumulated load, or ESAL, regression analyses of the plots were performed and smooth curves were developed. These curves are used in dTIMS® to predict the future performance of Arkansas' pavements, based on their cumulated ESALs.

dTIMS® Setup

Once the network was segmented and performance curves were developed, dTIMS® was ready to be setup. The following preliminary steps were taken before data was actually input into dTIMS®.

- 1) Define naming convention: Element identifiers and filters
- 2) Define list of treatments: What treatments will be applied?

- 3) Define data fields required for cost analysis: How will treatment costs be calculated?
- 4) Define expressions used for cost analysis: What are the cost formulas, if any?
- 5) Define list of triggers: When will treatments be triggered for application?
- 6) Define data fields required for triggering: How will triggers be defined?
- 7) Define economic criteria: Inflation rate? Discount rate? Desired benefits?
- 8) Define performance curves: At least one curve for each performance field.
- 9) Define data fields required for performance curves: Which fields are used in the curves.
- 10) Create a document describing above: This serves as a great reference.

dtIMS® BASED PMS FOR INTERSTATE HIGHWAYS

Segmentation

Interstate Review Team

In 1996, the AHTD Interstate Review Team was directed to assess the condition of Arkansas' Interstate Highway System and provide recommendations for project prioritization and remedial action. During their study, the team researched the construction and rehabilitation history of each pavement original section, conducted a subjective field condition survey, and created a database to organize and manage the information collected from the research and field surveys. (3) First, each interstate route was divided according to original paving contract segments to ensure homogeneous segments. The original job number, name, log mile limits, typical section, and the completion date was recorded for every segment. Also, the job number, log mile limits, description, and completion date of the last rehabilitation project, if applicable, was recorded. Next, the five engineers traveled the interstate network in a van, rating the structural condition and ride quality of each pavement section. Finally, all collected data was organized and input into a database using Microsoft Excel, Table 1.

Table 1 – Interstate Review Team Database

OVERALL ORDER	INTST. ORDER	SECTION NO.	DIR.	ORIGINAL JOB	COMP. DATE	ORIGINAL LOG MILE	ORIGINAL LOG MILE	ORIGINAL JOB NAME	ROUT F	SECTIO N	ORIGINA LENGTH	ORIGINA SURFAC E
1	1	3001	EB	3601	65	0	0.3	TEXAS LINE INTERCHANGE	30	11	0.3	9" CRCP
2	2	3002	EB	3652	67	0.3	11.5	STATE LINE INTER - HOMAN	30	11	11.22	10" JRCP
3	3	3002A	EB	3652	67	0.3	11.5	STATE LINE INTER - HOMAN	30	11	11.22	10" JRCP
4	4	3003	EB	3666	67	11.52	16.67	HOMAN - RED RIVER BR.	30	11	5.15	10" JRCP
5	5	3004	EB	3589	67	16.67	17.72	RED RIVER BR. & APPROACH	30	12	1.05	10" JRCP
6	6	3005	EB	3678	68	17.72	22.2	FULTON - SHEPPARD SURFACING	30	12	4.51	10" JRCP

ORIGINAL BASE	ORIGINAL SUBBASE	REHAB JOB	REHAB DATE	SECTIO N LOG MILE	LENGTH	REHAB TYPE	STRUCT. C/A	RIDE RATING
4" CRUSHED STONE BASE CRSE	4"-8" SUBBASE	30149	96	0	0.3	0.3	A	4.6
6" PC STABILIZED BSE CRSE		30149	96	0.3	7.02	6.72	A	4.7
6" PC STABILIZED BSE CRSE		30149	96	7.02	11.5	4.48	C	4.6
6" PC STABILIZED BSE CRSE		30050	96	11.52	16.17	4.65	C	4.8
6" PC STABILIZED BSE CRSE		3971	91	16.89	22.19	5.3	C	2
6" PC STABILIZED BSE CRSE		30079	93	17.72	18.3	0.58	C	2.3

Last Rehabilitation as Primary Basis for Segmentation for dtIMS®

The intent of segmenting the network is to group the pavements into homogeneous sections or segments. All homogeneous segments should have the same basic roadway characteristics and construction history, in hoping that future performance of the pavements in the same homogeneous group are similar. Arkansas' Interstate network was segmented according to the following considerations:

- Route Number
- Direction
- Original Pavement
- Section Number

- Last Rehabilitation (Pavement Type)

The database from the Interstate Review Team Report provided the basis for segmentation. For the application of dTIMS® for Arkansas's PMS, AHTD decided to segment the interstate into the following five pavement types according to the most recent rehabilitation. Please note that all Interstate pavements in Arkansas were initially constructed with concrete.

- Original Pavements
- Thin overlay
- Thick overlay
- Concrete patching & restoration (CPR)
- Concrete overlay

Regardless of their original construction, these five pavement types are used to classify the dTIMS® interstate network segments. Next, the pavement types were segmented further according to their respective section number, original pavement surface, direction, and route number. Geo-political boundaries and other factors determine a highway section at the AHTD. If all categories for two consecutive segments were the same, the segments were combined to create one uniform segment.

Sometimes, beginning and ending log miles of consecutive segments did not match exactly. After further investigation, most gaps in the database occurred when data on pavements with no rehabilitation histories was omitted. Also, it should be noted that distress, IRI, and rutting data was not a basis for segmentation. A table and pie chart of the distribution of Interstate segments is included in Appendix A.

Performance and Distress Data

Once the network database was updated with homogenous segments, performance data fields were assigned to each segment. The performance data of Arkansas' Interstate pavements was gathered based on results from the Interstate Review Team and data collected with the ARAN vehicle. Ride rating, structural rating, roughness (IRI), and rutting (asphalt pavements only) are the performance data fields for AHTD's Interstate Pavement Management System.

Ride and Structural Rating (Review Team)

The Interstate Review Team database contains ride ratings and structural ratings for the whole interstate network. Some of the review team database records were combined in order to create one segment in the network database. When records were combined, their respective ride and structural ratings were averaged to create one ride and structural rating for the combined record.

IRI and Rutting (ARAN)

ARAN data is produced in the form of “.asf”(ASF) files. Each ASF file contains data for one section in 25-meter increments. In this research, the ASF files were combined into one file per interstate route. This file was then converted into miles as the network database uses log-miles for identity, and imported into a Microsoft Access database. To obtain a condition value for each segment, queries were performed on the database to average all the condition values between the beginning log-mile and ending log-mile for each segment. As a result, an IRI value and rutting measurement were obtained for each segment.

ARAN distress data is not used for Interstates in dTIMS®. Distress data is a very important part of a pavement management system. However, as distress can only be analyzed manually at the AHTD, data is only available for a portion of the interstate highways (log-mile direction). Therefore, structural rating can act as its replacement until sufficient distress data becomes available.

Traffic (ESAL) Data

Available Data

Traffic data is critical for the creation of the performance curves and inventory database. An equivalent single axle load (ESAL) was chosen as the representative traffic data field. ESAL’s are the indicator of the load history for each pavement in the network. AHTD Technical Services provided a chart with ESAL’s for fifteen stations along the interstate system. The chart reports a 10-year average annual ESAL for the fifteen stations. I-430, I-440, and I-540 were not included in this table. To obtain ESAL values for these pavement segments that do not have ESAL data, truck percentages and ADT counts for these segments were used to generate average annual ESAL values for 10-year groups. The following equation was used to calculate annual ESAL’s.

$$Yearly\ ESAL = (AADT) * (365) * (\%Truck) * (LR\ Split) * (Axle\ Equivalency) \dots\dots\dots(1)$$

This equation is the same equation used by dTIMS® to calculate yearly ESAL’s during an analysis. Table 2 is an excerpt from the table provided by Technical Services.

Table 2 – Interstate Average Annual ESAL’s

AVERAGE ANNUAL ESALs			
	1967-1976	1977-1986	1987-1996
Texarkana	915,420	1,232,970	2,580,185
Jct. SH 51	1,023,825	1,805,290	3,429,905
Social Hill	886,220	1,699,805	4,145,305
Little Rock	2,826,925	3,668,615	4,482,565
Alma	475,595	828,550	1,845,805
East Clarksville	1,024,920	1,514,020	2,625,445
Russellville	338,720	1,116,900	2,282,345
N. Little Rock	1,937,785	2,075,390	2,769,255
Lonoke	2,156,420	3,282,080	3,861,700
Brinkley	1,295,385	2,459,005	5,395,430
Palestine	1,732,290	3,047,020	5,397,620
West Memphis	1,166,175	2,264,095	4,429,640
West Memphis	2,046,920	2,739,690	3,906,960
Joiner	792,780	1,465,110	2,698,080
Blytheville	613,565	883,300	2,127,220

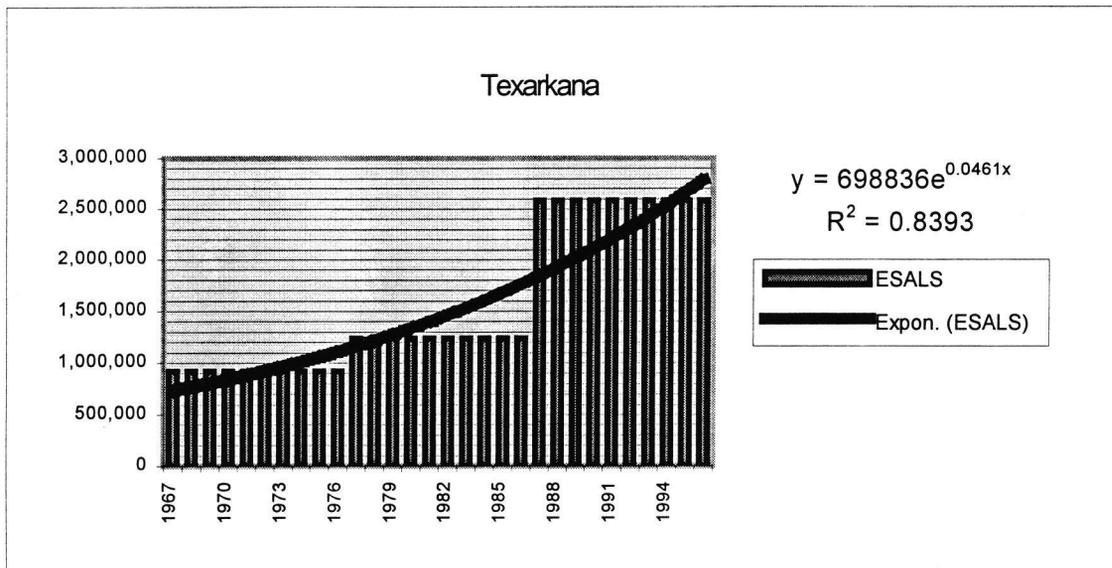


Figure 2 – Sample ESAL Station Regression Analysis

Method of Determination of ESAL's for Homogenous Segments

Regression analyses were performed on this data to retrieve yearly ESAL's at each station. A sample regression analysis can be seen in Figure 2. Once each station's yearly ESAL's were determined, linear interpolation was used to calculate the ESAL for every log mile between each station. However, a cumulative ESAL was necessary for each database segment. Cumulative ESAL's in a particular year was calculated by summing all yearly ESAL's before that year and since new construction or major rehabilitation. For example, the cumulative ESAL's since 1970 for a certain log mile would be the sum of that log mile's yearly ESAL's from 1970 to present. Since the network database is based on last rehabilitation, a cumulative ESAL for every segment can be determined by finding the cumulative ESAL's for that log mile from the year it was last rehabilitated. Original construction dates are used as the last rehabilitation date for original pavements.

As the traffic data for the Interstates is rather coarse, regression was used to back-calculate ESAL's for each year. In the future, more detailed traffic collection may be needed in order to have more precise data. Truck percentages were listed for all the years at each station. If ADT counts could be obtained, yearly ESAL's could be then calculated individually for each station. However, ESAL's for segments between stations would be calculated using the same approach.

Performance Curve Development

Types of Curves

Four performance curves were developed for each of the five interstate rehabilitation or pavement types. The four performance fields used are IRI, Rutting, Structural Rating (SRI), and Ride Rating (RRI). Each of the curves is a plot of the performance measurement vs. the pavement's accumulated load, or ESAL's. Figure 3 and Figure 4 are example performance curve plots. All the performance curve plots are included in Appendix C.

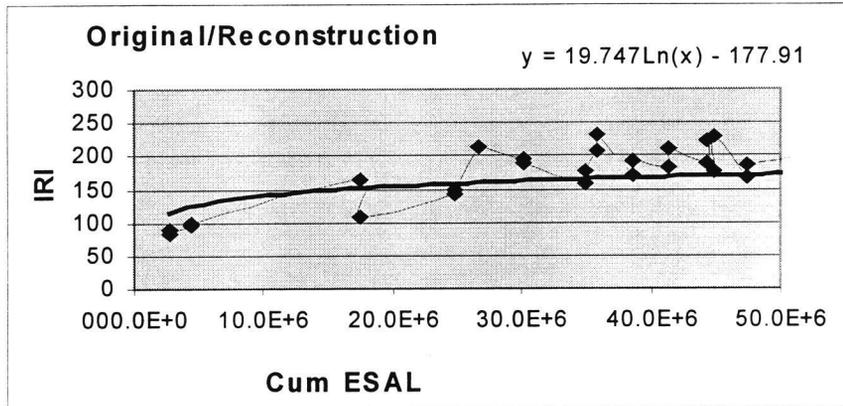


Figure 3 – IRI Performance Curve (Original Pavement)

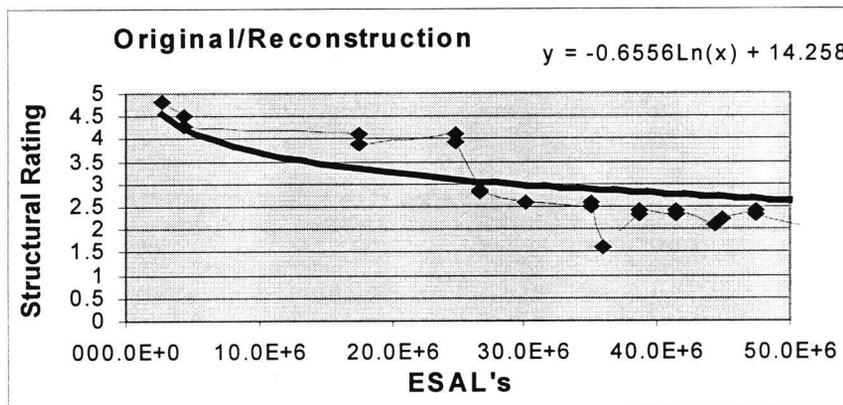


Figure 4 – SRI Performance Curve (Original Pavement)

Omitted Curve Types

Not every interstate segment falls into one of the five pavement types. For instance, some segments may have had a slurry seal applied. These pavements are classified as being rehabilitated with Ultra Thin rehabs. There were not enough segments of this type to develop performance curves. Therefore, the original (ORIG) performance curve is used to predict this pavement type's future condition. In addition, continuously reinforced concrete pavements (CRCP) were omitted from the data when the ORIG performance curve was developed. There were not enough CRCP segments to develop a curve. Instead, the ORIG curve is used for this data field.

PMS FOR NON-INTERSTATE (NHS)

Segmentation

Construction and rehabilitation histories of the Non-Interstate National Highway System (NHS) are not readily available at the AHTD. The establishment of the history data files would require too many resources to make it a practical effort in this project. Therefore, in order to segment the Non-Interstate NHS highways, a source of data containing sufficient road characteristics had to be obtained. The source of data used for this purpose was the AHTD Road Log. The Road Log is an inventory of Arkansas' state highway network. It contains a record for every road segment, bridge, box culvert, etc located in the network. A digital version of the Road Log in Microsoft ACCESS was obtained to query data and to generate segments.

First, all Non-Interstate NHS highway segments were extracted from the Road Log by querying for segments using two keys: Record Control 1 for Mileage and Federal Aid System (FASYS) 2 for Non-Interstate NHS. To reduce the file size of one file for the whole state, one data file was generated for each of the 10 districts. Each of the 10 files was converted into one Microsoft Excel workbook. To continue with the calibration methodology, seven Visual Basic for Applications (VBA) macros were written to sort through the 10 district files, split the network into homogeneous segments, search for IRI and rutting data, and calculate cumulative ESAL's.

Similar to the segmentation method used for the interstate highways, the Non-Interstate NHS segments were determined based on the Year Being Built (YRBLT) Road Log entry, or the year of the last rehabilitation or resurfacing of the segment. However, if segments with the same YRBLT had ADT's that differed by more than 50%, they were considered separate segments, primarily due to the belief that pavements with widely different ADT's may exhibit different performance characteristics. Furthermore, when segments do not have the same surface type (SURTY), section number (SECTN), or route number (ROUTE), the smallest segment used for dTIMS® was determined to be one half-mile. Table 3 shows the distribution of segments by surface type and functional classification.

Table 3 – NHS Segment Distribution

SEGMENT DISTRIBUTION													
Non-Interstate NHS Segments													
SURTY													
	30	42	51	61	62	63	64	65	66	67	71	72	73
FNCLA	2					88	16	325	61		12	15	4
	6					12	3	14	15		1		
	7					1	1	1	2				
	12					8		18	2		7	7	2
	14					11	3	37	21	1	6	1	
	16							1					

Following are the descriptions of the VBA macros used for segmentation.

Macro 1) The first macro splits each district into homogeneous segments. Each district was split in the order of these Road Log headings: ROUTE, SECTN, Surface Type (SURTY), YRBLT, and Average Daily Traffic (ADT). No segments have the same route number, the same section number, the same surface type, and the same year of last job. Data in the Road Log does not contain information on types of rehabilitation. Furthermore, the segmentation determines if the difference between two consecutive segments' ADT's was more than 50%.

Macro 2) The second macro combines segments if any segment is shorter than a half-mile. The small segment is combined with its previous or following segment according to which segment it most closely resembles. The order for comparison was route, section, surface type, year built, and ADT. If the segments compared equally, the small segment was combined with the smaller of the two adjacent segments.

Segments were combined according to ADT in the Road Log only if adjacent segments differed by less than 50%. The first and last segments in a group of combined segments might differ considerably. Also, distress, IRI, and rutting data is not used as a basis for Non-Interstate NHS segmentation, similar to the segmentation method used for interstate highways. A table and pie chart of the distribution of Non-Interstate NHS segments is included in Appendix A.

Performance Data

Roughness and Rutting (ARAN)

Performance data such as roughness and rutting was obtained from ARAN ASF files. AHTD Technical Services provided a CD with 1994 ASF files for the state of Arkansas. The CD contains a folder for every district. Each folder contains a file for every section of every route in that district. The VBA macro #3 finds the district, route, and section number for each segment and calculates its average IRI and average rutting measurement. Below is a description of the VBA macro used for querying performance data.

Macro 3) The third macro searches ARAN ASF files and averages roughness and rutting values for each segment.

Sometimes, an ASF file would be incomplete or contain blank values for some of its 25-meter measurements. In this case, zeros were used in the blank cells. Since each segment would be an average of no less than three hundred 25-meter measurements, the few zeros did not effect the final average. In addition, a few of the route/section files are not present on the CD. Therefore these segments were not used in determining performance curves. However, these segments are contained in the network database for dTIMS®' analysis, because they still belong to a pavement group and they do have cumulative ESAL's. The performance data for these segments are calculated based on the group's performance curves and the relevant ESAL's.

Traffic (ESAL) Data

Available Data

In order to develop performance curves, traffic information was needed to calculate cumulative ESAL's for each segment. The Road Log contained an AADT for each segment, but no other traffic information. To calculate ESAL's, truck percents and axle equivalencies (truck factors) were needed. Also, to calculate cumulative ESAL's, growth factors were used to back-calculate ESAL's of past years. Equation 1 was used to calculate a segment's annual ESAL.

Method of Determination

In AHTD there is a manual of Axle Distribution Tables and Load Equivalency Tables. Included in this manual are lookup tables for truck percentages for each functional classification, which were used to obtain truck percentages for each segment based on district and functional class. Table 4 and Table 5 were used to determine truck percentages for each segment based on its functional classification (FNCLA) in the Road Log entry.

Table 4 – Rural Areas – Truck Percent by Functional Classification, 1996

Functional	District	S/W Avg.										
A 01 – Interstate	45	N/M	37	38	N/M	36	43**	22	N/M	44	37	
B 02 – Principal	18	13	21	18	16	10	16	10	16	15	15	
C 06 – Minor	27	8**	33	8	15	4	13	11	9	20	21	
D 07 – Major	7	16	4	6	9	11	8	6	6	7	7	
E 08 – Minor	9	4	13	10	4	5**	11	4	7	10	9	
F 09 – Local	7	12**	4	9	11	4**	4	4	4	12	9	

* 1994 percentage
 ** 1995 percentage
 N/A – Data not
 N/M – No mileage in District
 Source: Vehicle Classification Summary, 1996, Technical

Table 5 – Urban Areas - Truck Percent by Functional Classification, 1996

Functional Class	District	S/W Avg.										
A 11 - Interstate	34	N/M	49	10	N/M	11	N/A	31	N/M	N/A	12	12
B 12 - Freeways &	N/A	24	18	12	18	8	19	N/A	12	*12	17	17
C 14 – Other Principal	11	5**	12	7	4	8	6	6	10	9	6	6
D 16 - Minor Arterials	10	3	5	7	8	6	6	6	4	2	6	6
E 17 - Collectors	8	5**	11	4	3	6**	5	5	5	3	6	6
F 19 - Local Streets	3	3**	8	9	9	6**	2	2	5	4	6	6

* 1994 percentage
 ** 1995 percentage
 N/A – Data not
 N/M - No mileage in
 Source: Vehicle Classification Summary, 1996, Technical Services

Note: The Needs database was initially going to be used to determine truck percents, however, the VBA macros were written for Non-Interstate NHS and Secondary routes. However, the Needs database doesn't contain any information on Secondary routes, so the lookup table was used to determine truck percentages for the Non-Interstate NHS. A macro to determine truck percents from the Needs database is also available, if needed. In the end, curves for Secondary roads are not used in dTIMS® analysis, primarily due to the fact that the developed curves do not appear to represent

realistic performances. As a matter of fact, analysis cannot be performed on Secondary roads. However, inventory data for Secondary roads was developed in this research and are available to be used.

AHTD Axle Distribution and Load Equivalency Tables for different functional classes were used to determine the values of Axle Equivalency, or Axle Equivalency Factor (AEF), in equation 1. AHTD uses a macro to calculate a pavement's yearly ESAL. This macro takes inputs of an average ADT, a truck percent, what axle distribution table to be used, and what load equivalency factor (LEF) table to be used. The axle distribution table and LEF are used to obtain AEFs. Each functional classification has a unique axle distribution table. Also, in the AHTD manual, there are different load equivalency factor tables for asphalt structural numbers from 4 – 6 and concrete thicknesses from 9 - 12.

However, there are about 700 Non-Interstate NHS segments in Arkansas. It would be time prohibitive to run the Macro 700 times to obtain AEFs for just one year. An alternative method was devised in this study to efficiently obtain AEFs for every segment. It was determined that in the process of determining values of Axle Equivalency, the effect of actual values of ADT and truck percentages on the final AEFs is minimal, primarily due to the fact that passenger vehicles do not materially affect the values of Axle Equivalency.

Therefore, the goal is to develop one uniform AEF for each functional class. ESALs were calculated based on imaginary ADT's and truck percents. Next, the calculated ESAL was divided by the number of trucks. This quotient is the axle equivalency factor, AEF for this particular functional class. No matter what ADT or truck percent is used, the value of the factor will essentially remain the same. The passenger vehicle percentage would cause a difference in the calculations. However, the passenger vehicle factor is so small that it has a minimal affect on the calculated ESAL (less than 0.1%).

In addition, since there are several LEF tables for various pavement types (six for concrete and three for asphalt), modifications are needed to obtain the final uniform AEF for pavements in one functional class. For instance, the calculated AEF changes somewhat dependent on what LEF is used. LEFs are obtained from the AHTD manual based on structural number for asphalt pavements, or concrete thickness for concrete pavements. Therefore, the final AEF was averaged based on the AEFs for all of the different LEF tables, resulting in one asphalt AEF and one concrete AEF for each functional class in the network. Table 6 lists the calculated axle equivalency factors.

Table 6 – Axle Equivalencies

Axle Equivalency Table				
RURAL	Distribution Table	Functional Class	Asphalt	Concrete
Interstate	5	1	1.025	1.542
Principle Arterial	22	2	0.85	1.372
Minor Arterial	48	6	0.877	1.372
Collectors	73	7 & 8	0.921	1.536
URBAN	Distribution Table	Functional Class	Asphalt	Concrete
Interstate/Freeway	6	11 & 12	0.725	1.086
Principle Arterial	46	14	1.034	1.62
Other Arterials	85	16 & 17	0.725	1.086

In order to derive ESAL's of segments for every year for cumulative ESAL's, growth rates were used. AHTD Technical Services provided Table 7, which includes ADT growth rates for each functional classification.

Table 7 -- ADT Growth Rates by Functional Class

ADT Growth Rates by Functional Class		
	Functional Class	ADT Growth Rate
	1	3.0%
	2	2.8%
RURAL	6	2.5%
	7	2.0%
	8	1.8%
	9	1.5%
	11	2.8%
	12	2.6%
URBAN	14	2.5%
	16	2.5%
	17	2.0%

These growth rates were used to back-calculate a segment's ADT to the year entered in its YRBLT entry in the Road Log. Then, yearly ESAL's were calculated for each of these years. Next, a cumulative ESAL was calculated by summing all of the yearly ESAL's for that segment.

Following are descriptions of the numbered VBA macros used for traffic data determination.

Macro 4) The fourth macro determines truck percents for each segment. Two tables provided by Technical Services were used to determine the truck percents. The tables list truck percents by functional class for each district. (Initially, the "Needs Database" was used, however, not all of the secondary pavements are included in this database.)

Macro 5) The fifth macro calculates the yearly Equivalent Single Axle Load (ESAL) for each segment in its ADT year. Each segment's ADT was taken in a different year, so the ESAL is calculated for that specific year. The ESAL is calculated using equation 1.

Macro 6) The sixth macro calculates cumulative ESAL's for each of the segments. An ESAL and cumulative ESAL is calculated for 1997 and 1994 (the year of the ARAN data, for purpose of making p-curves). The 94 & 97 ESAL's are calculated by interpolating from the ADT-year ESAL using a growth rate. A table of growth rates for each functional class was provided by Technical Services. The cumulative ESAL's were determined by calculating and summing the yearly-ESAL's from 1994/1997 to the YRBLT.

Macro 7) The seventh macro combines the completed district files into one large file for Non-Interstate NHS segments.

There are some issues with the methodology used to determine ESAL's. For instance, the yearly ESAL's were determined from the YRBLT Road Log entry. The meaning of YRBLT may affect the ESAL's. Also, when calculating the yearly ESAL's,

an equivalency factor of 0.0004 can be multiplied by the percent of passenger vehicles. This might have made a difference big enough to affect the final AEFs when there is an unusually large passenger vehicle percentage. Furthermore, the NEEDS database or some other database could be used to more accurately determine a segment's truck percent. Currently, truck percents are determined according to a pavement's functional classification and district. A more site-specific method needs to be developed to obtain truck percentages for individual segments.

Performance Curve Development

Curve Types

Two performance curves, IRI and rutting, were developed for seven different NHS pavement groups. Seven pavement groups were determined according to a pavement's surface classification and functional classification. Table 8 lists the seven Non-Interstate NHS pavement groups.

Table 8 – Non-Interstate NHS Pavement Groups

Group	Surface Classification	Functional Classification
1_00	Concrete (1)	All
2_00	Asphalt (2)	All
2_02	Asphalt (2)	2
2_06	Asphalt (2)	6
2_12	Asphalt (2)	12
2_14	Asphalt (2)	14
3_00	Asphalt over Jointed Concrete (3)	All

The concrete and asphalt classifications were determined using the SURTY (surface type) Road Log entry. The surface classification of the asphalt over jointed concrete was determined by engineering judgment based on experience. Four highways were considered as old jointed concrete pavements. If the Road Log classified these segments as asphalt, then they were considered to be asphalt/jointed concrete pavements. Otherwise they were classified as concrete. Many different combinations could have been created for the development of the Non-Interstate NHS performance curves. The generic classification (i.e. asphalt, concrete, asphalt/jointed) of the segments causes the data points on the curves to be very scattered, due to the lack of sufficient pavement history for the Non-Interstate NHS routes. Therefore, seven final curves were developed after studying the distribution of segments of various surface types, surface classifications, functional classes, etc. Pavements that do not have a curve for their functional classification will use the 'All' functional classification curve for their respective surface classification.

Figure 5 and Figure 6 are examples of the developed performance curve plots.

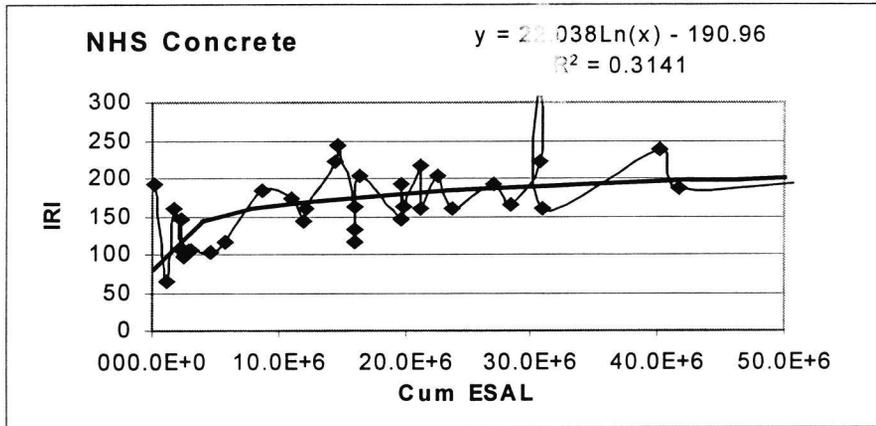


Figure 5 – IRI Performance Curve (Concrete, FNCLA All)

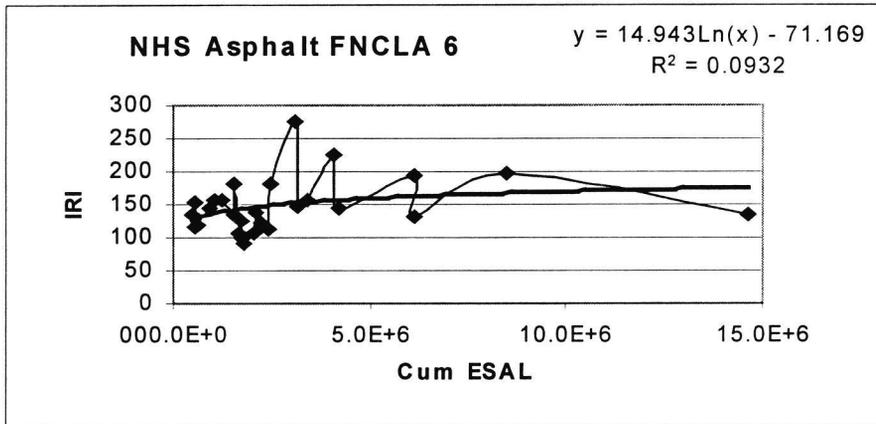


Figure 6 – IRI Performance Curve (Asphalt, FNCLA 6)

CONFIGURATION OF dTIMS® FOR THE STATE OF ARKANSAS

Inventory File

The inventory file is the most fundamental file in dTIMS®. It contains descriptions of every element in the network and defines the performance data fields to be used during analysis. The inventory file structure must be created in dTIMS® setup before any importing takes place. The inventory file can be imported from Access, Excel, or dROAD, and can also be input directly in dTIMS®. The AHTD network inventory is a Microsoft Excel file. It contains every segment for Interstates and Non-Interstate routes, along with any pertinent information for that segment, all of which was determined as discussed in previous sections. There is only one inventory file established for the Arkansas PMS for both interstate highways and non-interstate highways of the National Highway System (NHS). The following is a complete list of the current inventory file data fields and their descriptions.

- FSECTION -- Unique identifier
- FLENGTH -- Length of the element
- FNAME -- Route name
- FOFFFROM -- From log-mile
- FOFFTO -- To log-mile
- FDESCFROM -- Description of FOFFFROM
- FDESCTO -- Description of FOFFTO
- AADT -- Annual Average Daily Traffic
- CUM_ESAL -- Initial cumulative ESAL
- AXLEQUIV --Axle Equivalency factor
- LRSPLIT -- Left/Right directional split
- COM_TRT -- Committed treatment
- COM_COST -- Committed cost of COM_TRT
- COM_YEAR -- Committed year of COM_TRT
- COM_BUDG -- Committed Budget of element
- TRAV_WAY -- Width of pavement
- PCT_COMM -- Percent commercial vehicles
- YR_LSTWK -- Year of last work
- ISINFILTER -- Internal filter used by dTIMS®
- DSTNO -- District Number
- CONTY -- County Number
- SECTN -- Section Number

- LAWID -- Lane Width
- FNCLA -- Functional Classification
- YRADT -- Year of ADT count
- SURTY -- Surface Type from Road Log (Non-Interstate)
- FASYS -- Highway System
- PVMT_SURF -- Pavement Surface:
(1) Concrete, (2) Asphalt, (3) Asphalt/Jointed - (Non-Interstate)
- IRI -- International Roughness Index
- RUT -- Rutting Measurement
- SRI -- Structural Rating Index (Interstate)
- RRI -- Ride rating Index (Interstate)
- REH_TYPE -- Rehabilitation Type (Interstate)

The FLENGTH, FOFFFROM, and FOFFTO values must be integers. The values in these three data fields have been multiplied by 100 in the EXCEL worksheet, as decimal numbers are not used in the three fields of dTIMS®. The decimals will be automatically created when the values are exported into dTIMS®.

In addition, when creating the inventory data fields, an inventory database field property window should be available. One of this window's options allows the user to edit the database column headings. Due to a programming bug, this window was not available in dTIMS® when the inventory database was created. The problem was solved using the following method. Please note that newer versions of dTIMS® may have solved this problem.

- 1) Backup the database and close dTIMS®.
- 2) Open the dBase file 'DT0ITM.DBF' in the database directory.
- 3) Find the column headings and edit them accordingly.

When importing from Excel, the inventory file structure must first be created in dTIMS® then exported to a blank Excel file. The new Excel file will contain only the exported data field headings. Next, the file can be filled via copy/paste according to the data field headings. Make sure that if a data field has any entries, the rest of that data field's column must contain some sort of null value, otherwise a numeric overflow error will occur. Zeros and "N/A" are used for null values in the AHTD inventory EXCEL worksheet before importing. At this stage, the new Excel inventory file can be imported into dTIMS®.

Configuration Options

The dTIMS® ‘Options’ window includes system as well as analysis parameters. The data is presented using four tabs: (1) General, (2) Network Impact, (3) Analysis Parameters, and (4) Economic Parameters.

General

The unit of measure for Arkansas’ PMS is the mile (mi.) The number of units in length and offset values is 2. The offset value is used in dTIMS® to generate correct decimal numbers for length values that were integer values in EXCEL worksheet. The unit for displaying costs will be dollars (\$).

Network Impact

The performance index used to measure network impacts is chosen in this tab. The performance variable used in this PMS is the Pavement Condition Rating (PCR). PCR represents a type of composite rating for pavement performance and condition. The PCR must be declared in the Inventory Database Fields library window in dTIMS® setup. Two filters will be used for calculating PCR. One filter identifies the Interstate routes while the other filter identifies Non-Interstate NHS routes. There are two different PCR equations because the Interstates have a Ride rating and a Structural Rating, which are not present with Non-Interstate NHS routes. Therefore, different expressions are used to calculate the PCR for Interstate and Non-Interstate NHS pavements. Table 9 shows the two equations used to calculate PCR. Figure 7 is a plot of the Non-Interstate NHS expression.

Table 9– Network PCR Expressions

Highway System	Expression Name	Expression
Interstate	PCR_INT	$(SRI + RRI) / 10$
Non-Interstate	PCR_NHS	$(-0.0001 * (IRI) * (IRI) - 0.2945 * (IRI) + 99.336)$

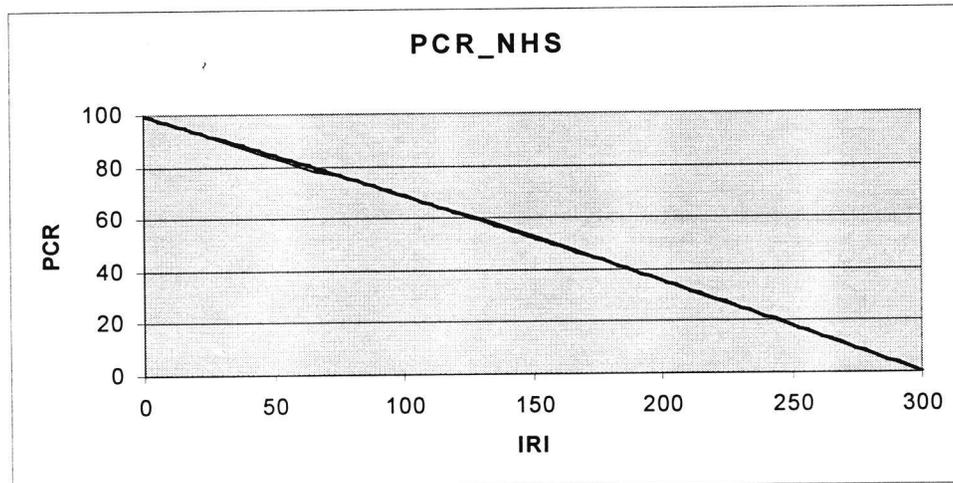


Figure 7 – PCR vs. IRI (Non-Interstate NHS)

Analysis Parameters

The Analysis Parameters tab supplies the beginning and ending year of the analysis period along with the last year that treatments can be applied. The beginning and ending years for sample analyses are 1997 and 2037 respectively. The last year to apply treatments is 2017. Also included is the choice of geometric or arithmetic growth for traffic factors. Arithmetic growth is used in the sample analyses.

Economic Parameters

In the Economic parameters tab, the discount and inflation rates are input. The discount rate is the rate used to reduce future costs or benefits to a present day value, and the inflation rate is the rate used to inflate treatment costs. No research was performed for these values but they can be easily changed. The discount and inflation rates used for sample analyses are 4% and 2% respectively.

Naming Conventions

FSECTION

dTIMS® requires a ten digit unique identifier for every element (segment) in the network. The following naming convention is used for Arkansas' Interstate and Non-Interstate (NHS) network segments.

- Interstate: (Route Name)+(Section #)+(Direction: 1=Log, 2=Anti-Log)+(Begin Mile)

For Begin Mile, consider one decimal place, but do not use the decimal point. For instance, Begin Mile 12.33 is represented by 0123.

Route	Section	Dir.	Begin-Mile
↓	↓	↓	↓
430	03	1	0120

- Non-Interstate: (Route Name)+(Section #)+(Description)+(Begin Mile)

Route	Section	Desc.	Begin-Mile
↓	↓	↓	↓
065	12	A	0013

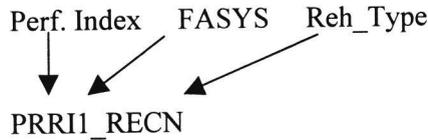
Note: The 'Description' convention is the same as used in the Road Log description under the Section (SECTN) heading. A, B, L, and S are for alternate, business, loop, and spur routes respectively. A '1' is used as the description for routes with no alternate section.

Expression Names

Expressions in this system are only used for performance curves. A 'P' at the beginning of each expression is used to represent performance curves. The following

convention is used for names for performance curves for Interstate and Non-Interstate NHS routes:

- Interstate – P(Index Name)(FASYS)_(REH_TYPE)



- Non-Interstate NHS – P(Index Name)(FASYS)_(PVMT_SURF)_(FNCLA)

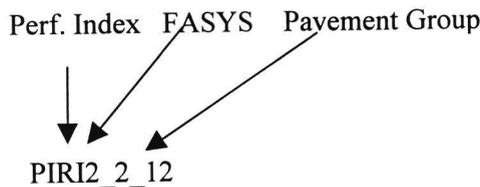


Table 10 -- Filters and Expressions for Performance Curves

Filters and Expressions for Performance Curves			
Filter Name	Filter	Expression Name	Expression
P1_COVL	FASYS = 1 AND REH_TYPE = 'Concrete'	PSR11_COVL	-0.6851*LOG(GCUMESAL)+14.548
P1_CPRS	FASYS = 1 AND REH_TYPE = 'CPR'	PSR11_CPRS	-0.4071*LOG(GCUMESAL)+9.4109
P1_REC�	FASYS = 1 AND REH_TYPE = 'Orig'	PSR11_REC�	-0.6556*LOG(GCUMESAL)+14.258
P1_THIK	FASYS = 1 AND REH_TYPE = 'Thick'	PSR11_THIK	-0.4257*LOG(GCUMESAL)+11.032
P1_THIN	FASYS = 1 AND REH_TYPE = 'Thin'	PSR11_THIN	-0.3718*LOG(GCUMESAL)+9.615
P1_COVL	FASYS = 1 AND REH_TYPE = 'Concrete'	PRR11_COVL	-0.6292*LOG(GCUMESAL)+13.338
P1_CPRS	FASYS = 1 AND REH_TYPE = 'CPR'	PRR11_CPRS	-0.3465*LOG(GCUMESAL)+7.7269
P1_REC�	FASYS = 1 AND REH_TYPE = 'Orig'	PRR11_REC�	-0.6783*LOG(GCUMESAL)+14.113
P1_THIK	FASYS = 1 AND REH_TYPE = 'Thick'	PRR11_THIK	-0.3108*LOG(GCUMESAL)+9.0478
P1_THIN	FASYS = 1 AND REH_TYPE = 'Thin'	PRR11_THIN	-0.3223*LOG(GCUMESAL)+8.7067
P1_COVL	FASYS = 1 AND REH_TYPE = 'Concrete'	PIR11_COVL	15.793*LOG(GCUMESAL)-121.6
P1_CPRS	FASYS = 1 AND REH_TYPE = 'CPR'	PIR11_CPRS	1.3168*LOG(GCUMESAL)+150.16
P1_REC�	FASYS = 1 AND REH_TYPE = 'Orig'	PIR11_REC�	19.747*LOG(GCUMESAL)-177.91
P1_THIK	FASYS = 1 AND REH_TYPE = 'Thick'	PIR11_THIK	16.798*LOG(GCUMESAL)-193.66
P1_THIN	FASYS = 1 AND REH_TYPE = 'Thin'	PIR11_THIN	11.143*LOG(GCUMESAL)-62.062
P2_1_00	FASYS = 2 AND SURF_CLASS = 1	PIR12_1_00	22.038*LOG(GCUMESAL) - 190.96
P2_2_00	FASYS = 2 AND SURF_CLASS = 2	PIR12_2_00	6.8378*LOG(GCUMESAL) + 32.107
P2_2_02	FASYS = 2 AND FNCLA = 2 PVMT_SURF = 2	PIR12_2_02	4.7907*LOG(GCUMESAL) + 54.455
P2_2_06	FASYS = 2 AND FNCLA = 6 AND PVMT_SURF = 2	PIR12_2_06	14.943*LOG(GCUMESAL) - 71.169
P2_2_12	FASYS = 2 AND FNCLA = '12' SURF_CLASS = 2	PIR12_2_12	13.746*LOG(GCUMESAL) - 75.004
P2_2_14	FASYS = 2 AND FNCLA = '14' SURF_CLASS = 2	PIR12_2_14	12.809*LOG(GCUMESAL) - 18.525
P2_3_00	FASYS = 2 AND SURF_CLASS = 3	PIR12_3_00	6.694*LOG(GCUMESAL)+34.323
P1_THIK	FASYS = 1 AND REH_TYPE = 'Thick'	PIR11_THIK	16.798*LOG(GCUMESAL)-193.66
P1_THIN	FASYS = 1 AND REH_TYPE = 'Thin'	PIR11_THIN	11.143*LOG(GCUMESAL)-62.062
P2_2_00	FASYS = 2 AND SURF_CLASS = 2	PIR12_2_00	6.8378*LOG(GCUMESAL) + 32.107
P2_2_02	FASYS = 2 AND FNCLA = 2 PVMT_SURF = 2	PIR12_2_02	4.7907*LOG(GCUMESAL) + 54.455
P2_2_06	FASYS = 2 AND FNCLA = 6 AND PVMT_SURF = 2	PIR12_2_06	14.943*LOG(GCUMESAL) - 71.169
P2_2_12	FASYS = 2 AND FNCLA = '12' SURF_CLASS = 2	PIR12_2_12	13.746*LOG(GCUMESAL) - 75.004
P2_2_14	FASYS = 2 AND FNCLA = '14' SURF_CLASS = 2	PIR12_2_14	12.809*LOG(GCUMESAL) - 18.525
P2_3_00	FASYS = 2 AND SURF_CLASS = 3	PIR12_3_00	6.694*LOG(GCUMESAL)+34.323

Filter Names

Similar to expressions, filters have a significant letter at the beginning. The letter symbolizes what the filter is for. For instance, a trigger filter will have 'T' at the beginning. Table 11 briefly describes the filter naming convention.

Table 11 -- Filter Naming Convention

Filter Type	Convention	Example
Performance Curve (INT)	P(FASYS)_(REH_TYPE)	P1_THIN
Performance Curve (Non-Interstate)	P_(FASYS)_(PVMT_SURF)_(FNCLA)	P2_2_12
Trigger (INT)	T_(Treatment Code)_(REH_TYPE)	T_THIN_ORG
Trigger (Non-Interstate)	T_(Treatment Code)_(FNCLA)	T_OVL1
Analysis Set	A_(Highway System)	A_NHS
Growth Rate	G_(Functional Classification)	G_FNCLA_12

An Error in dTIMS® and Performance Curves

The independent variable for performance curves is cumulative ESAL's. The CUM_ESAL data field in the inventory file is the initial cumulative ESAL of the element. The variable that is used for the performance curve expressions is the runtime variable called GCUMESAL. A runtime variable is a variable calculated internally by dTIMS® during the generation of strategies. GCUMESAL is recalculated every analysis year as the sum of the previous GCUMESAL and the runtime variable GYRLYESAL. GYRLYESAL is the number of ESAL's applied to an element in the current analysis year. While entering expressions in dTIMS®, an error occurs when choosing GCUMESAL as a variable. A patch for the software is currently being developed to correct this error. In the meantime, the problem is solved as follows:

- 1) Input a dummy variable for GCUMESAL in the expression builder.
- 2) Backup the database and close dTIMS®.
- 3) Open the dBase file 'DT0FRM.DBF'
- 4) Find the correct expression and replace the dummy variable with GCUMESAL

A decision tree determines which performance curve is applied to which element. Filters are used to narrow down elements and choose the correct pavement type/rehab curve. Table 12 lists the performance curve filters and expressions used for each performance data field. The decision trees for Arkansas' performance indices are included in Appendix B.

Table 12 – Performance Curves for dTIMS®

Performance Curves					
Index	Filter Name	Expression Name	System (FASYS)	Surface	FNCLA
SRI	P1_COVL	PSRI1_COVL	INT (1)	Concrete	All
	P1_CPRS	PSRI1_CPRS	INT (1)	Concrete	All
	P1_REC�	PSRI1_REC�	INT (1)	Concrete	All
	P1_THIK	PSRI1_THIK	INT (1)	Asphalt	All
	P1_THIN	PSRI1_THIN	INT (1)	Asphalt	All
RRI	P1_COVL	PRRI1_COVL	INT (1)	Concrete	All
	P1_CPRS	PRRI1_CPRS	INT (1)	Concrete	All
	P1_REC�	PRRI1_REC�	INT (1)	Concrete	All
	P1_THIK	PRRI1_THIK	INT (1)	Asphalt	All
	P1_THIN	PRRI1_THIN	INT (1)	Asphalt	All
IRI	P1_COVL	PIRI1_COVL	INT (1)	Concrete	All
	P1_CPRS	PIRI1_CPRS	INT (1)	Concrete	All
	P1_REC�	PIRI1_REC�	INT (1)	Concrete	All
	P1_THIK	PIRI1_THIK	INT (1)	Asphalt	All
	P1_THIN	PIRI1_THIN	INT (1)	Asphalt	All
	PIRI2_1_00	PIRI2_1_00	NHS (2)	Concrete	All
	PIRI2_2_00	PIRI2_2_00	NHS (2)	Asphalt	All
	PIRI2_2_02	PIRI2_2_02	NHS (2)	Asphalt	2
	PIRI2_2_06	PIRI2_2_06	NHS (2)	Asphalt	6
	PIRI2_2_12	PIRI2_2_12	NHS (2)	Asphalt	12
PIRI2_2_14	PIRI2_2_14	NHS (2)	Asphalt	14	
PIRI2_3_00	PIRI2_3_00	NHS (2)	Asphalt/JCP	All	
RUT	P1_THIK	PIRI1_THIK	INT (1)	Asphalt	All
	P1_THIN	PIRI1_THIN	INT (1)	Asphalt	All
	PIRI2_2_00	PIRI2_2_00	NHS (2)	Asphalt	All
	PIRI2_2_02	PIRI2_2_02	NHS (2)	Asphalt	2
	PIRI2_2_06	PIRI2_2_06	NHS (2)	Asphalt	6
	PIRI2_2_12	PIRI2_2_12	NHS (2)	Asphalt	12
	PIRI2_2_14	PIRI2_2_14	NHS (2)	Asphalt	14
	PIRI2_3_00	PIRI2_3_00	NHS (2)	Asphalt/JCP	All

Treatments

Interstate Treatments

The treatments available for interstate pavements are a thick and a thin overlay. For simplicity, only two treatments were used and both treatments are considered rehabilitation treatments. Both treatments will reset all the performance data fields (condition ratings) and reset the cumulative ESAL's. Also, the REH_TYPE data field will be reset to the correct treatment. Other treatments, such as CPR, reconstruction, or crack sealing, can be added as needed. Further research into triggers and condition/ESAL resets will need to take place before other treatments are used.

Non-Interstate (NHS) Treatments

The only available treatment for Non-Interstate pavements is a structural overlay. Each of the three Non-Interstate surface types has its own overlay treatment, resulting in three separate treatment names: OVL1, OVL2, and OVL3. Three separate treatment names are used so different costs and resets can be applied to each of the different surface types. Interstate and Non-Interstate (NHS) treatment codes, costs, and resets are listed in Table 13.

Table 13 – Treatment Codes, Costs, and Resets

Treatment Codes, Costs, and Resets				
Treatment Description	Code	Cost / mi.	Reset variable	Reset
Thick Ovly / Thin	THIK	600,000	REH_TYPE	THIK
Thick Ovly / Thik	THIK	600,000		
Thick Ovly / Orig	THIK	600,000	REH_TYPE	THIK
Thick Ovly / CPR	THIK	600,000	REH_TYPE	THIK
Thick Ovly / Covl	THIK	600,000	REH_TYPE	THIK
Thin Ovly / Thin	THIN	300,000		
Thin Ovly / Thik	THIN	300,000	REH_TYPE	THIN
Thin Ovly / Orig	THIN	300,000	REH_TYPE	THIN
Thin Ovly / CPR	THIN	300,000	REH_TYPE	THIN
Thin Ovly / Covl	THIN	300,000	REH_TYPE	THIN
Str. Ovly / NHS 1	OVL1	300,000	SURTY SURF_CLASS	60 3
Str. Ovly / NHS 2	OVL2	300,000	SURTY	60
Str. Ovly / NHS 3	OVL3	300,000	SURTY	60

The descriptions of the treatments describe what treatment is applied to what pavement group. For instance, “Str. Ovly / NHS 2” is a structural overlay over a Non-Interstate NHS segment with a surface classification (SURF_CLASS) of 2. “Thick Ovly / Thin” is a thick overlay over an interstate segment with a last rehabilitation (LAST_REHAB) of “THIN”.

Budget Categories

Budget categories provide a method to allocate portions of a budget towards certain elements, groups, highways, etc. Each treatment has a budget category assigned to it, and each category has its own budget. Two categories were created for Arkansas’ PMS, Interstate and Non-Interstate NHS. The available treatments are specific to one highway system, so they are assigned to that specific budget category. A general budget category named capital (CAP) was created to run an analysis with no separation of funding, just one budget. To do this, the treatments will need to be changed to the CAP budget category.

Triggers

For the purposes of sample analyses, trigger values were determined based on judgement. The values may be changed easily so analyses of different triggers may be performed. Filters are used to decide what condition ratings will trigger a treatment and also to make sure an Interstate treatment is not applied to a Non-Interstate pavement and vice versa. Table 14 lists the triggers used for each rehabilitation treatment in dTIMS®. Table 15 was used for determining IRI triggers.

Table 14 – Trigger Filters

Trigger Filters		
Treatment Code	Filter Name	Filter
THIK	T_THIK_THN	RRI < '2.8' AND SRI < '2.8' AND IRI > '135'
THIK	T_THIK_THK	RRI < '2.8' AND SRI < '2.8' AND IRI > '135'
THIK	T_THIK_ORG	SRI < '3' AND
THIK	T_THIK_COV	SRI < '3' AND
THIN	T_THIN_THN	RRI < '3.3' AND SRI < '3.3' AND IRI > '105'
THIN	T_THIN_THK	RRI < '3.3' AND SRI < '3.3' AND IRI > '105'
THIN	T_THIN_ORG	SRI < '3.5' AND
THIN	T_THIN_COV	SRI < '3.5' AND
OVL1	T_OVL1_00	IRI > '125'
OVL2	T_OVL2_02	IRI > '125'
OVL2	T_OVL2_06	IRI > '125'
OVL2	T_OVL2_12	IRI > '125'
OVL2	T_OVL2_14	IRI > '125'
OVL3	T_OVL3_00	IRI > '125'

Table 15 – International Roughness Index Scale

International Roughness Index Scale				
Condition	Interstate		Other Roads	
	PSR	IRI	PSR	IRI
Very Good	4.0 - 5.0	< 60	4.0 - 5.0	< 60
Good	3.5 - 3.9	60 - 94	3.5 - 3.9	60 - 94
Fair	3.1 - 3.4	95 - 119	2.6 - 3.4	95 - 170
Mediocre	2.6 - 3.0	120 - 170	2.1 - 2.5	171 - 220
Poor	0.0 - 2.5	> 170	0.0 - 2.0	> 220

Traffic Growth

Traffic growth in this system is based on functional classification. The ADT growth rates used for cumulative ESAL calculation are also used as the ADT growth rates in dTIMS®. The axle equivalencies do not have growth rates, which can be added to the system in the future. Filters determine what the functional class of the element is and therefore what growth rate to apply. Table 16 lists the filters for traffic growth rates.

Table 16 – Traffic Growth Rate Filters

Traffic Growth Rate Filters			
Functional Class	Rate	Filter Name	Filter
01	3.0	G_FNCLA_01	FNCLA = '01'
02	2.8	G_FNCLA_02	FNCLA = '02'
06	2.5	G_FNCLA_06	FNCLA = '06'
07	2.0	G_FNCLA_07	FNCLA = '07'
08	1.8	G_FNCLA_08	FNCLA = '08'
09	1.5	G_FNCLA_09	FNCLA = '09'
11	2.8	G_FNCLA_11	FNCLA = '11'
12	2.6	G_FNCLA_12	FNCLA = '12'
14	2.5	G_FNCLA_14	FNCLA = '14'
16	2.5	G_FNCLA_16	FNCLA = '16'
17	2.0	G_FNCLA_17	FNCLA = '17'

dTIMS® SAMPLE RUNS AND ANALYSIS

Analysis Sets

Three Analysis Sets are used for some sample analyses. Table 17 lists the sample Analysis Sets.

Table 17 – Analysis Sets

Analysis Sets		
Description	Filter Name	Filter
All Roads	ALL_ROADS	1 = 1
Interstate	A_INT	FASYS = '1'
Non-Interstate NHS	A_NHS	FASYS = '2'

Each analysis set contains different budget scenarios and splits the budget into budget categories. Table 18, Table 19, and Table 20 report the budget scenarios for each of the three Analysis Sets. The yearly budgets for each budget category is also included for each scenario.

Table 18 – All_Roads Analysis Set (ALL_ROADS)

Budget Category	Scenario		
	Do-Nothing	Unlimited	1 Billion
INTS	0	999,999,999	35,000,000
NHS	0	999,999,999	965,000,000
CAP	0	0	0
Total	0	1,999,999,998	1,000,000,000

Table 19 – Interstate Analysis Set (A_INT)

Budget Category	Scenario		
	Do-Nothing	Unlimited	35 Million
INTS	0	999,999,999	35,000,000
NHS	0	0	0
CAP	0	0	0
Total	0	999,999,999	35,000,000

Table 20– Non-Interstate NHS Analysis Set (A_NHS)

Budget Category	Scenario				
	Do-Nothing	Unlimited	750 Million	100 Million	50 Million
INTS	0	0	0	0	0
NHS	0	999,999,999	750,000,000	100,000,000	50,000,000
CAP	0	0	0	0	0
Total	0	999,999,999	750,000,000	100,000,000	50,000,000

Generation of Strategies

To generate strategies, switch to the Analysis mode, close the inventory file window, and choose Tools -- Generate Strategies. Generate Strategies determines every possible strategy for every element in the network. Strategies may be developed for certain Analysis Sets by choosing the set from a drop down list. During the sample analyses, Generate Strategies was performed on each of the three Analysis Sets.

Optimization

Optimization determines the incremental benefit cost for each element and chooses a 'Selected Strategy'. The optimization was performed directly after strategy generation by choosing the checkbox in the Generate Strategies Window. Figure 8, and Figure 9 are dTIMS® created graphs of the optimization of the A_INT Analysis Set using the '35 Million' budget scenario.

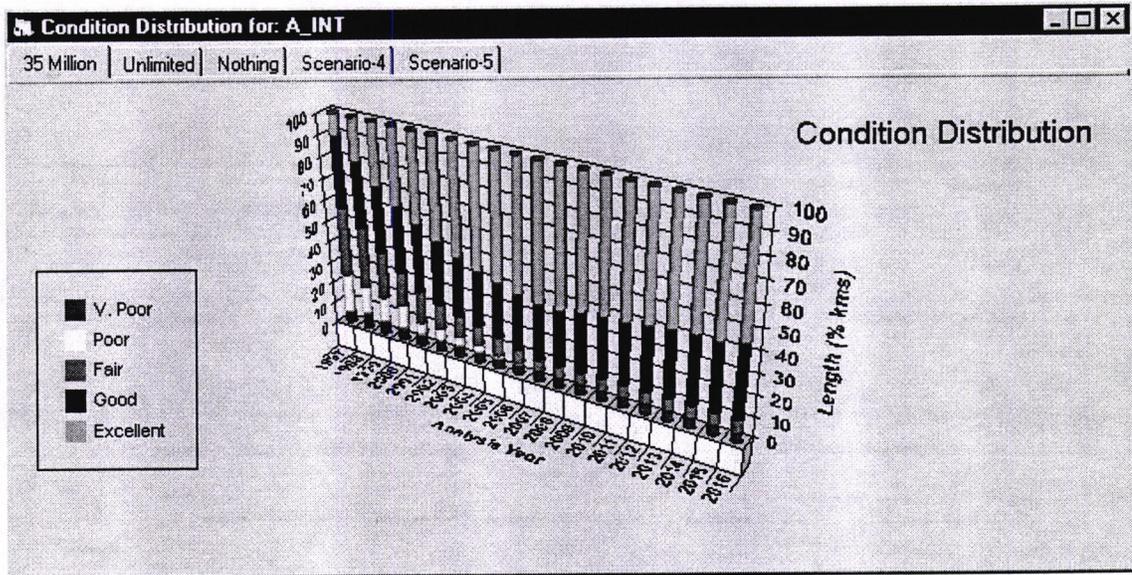


Figure 8 – Sample Analysis Condition Distribution Graph

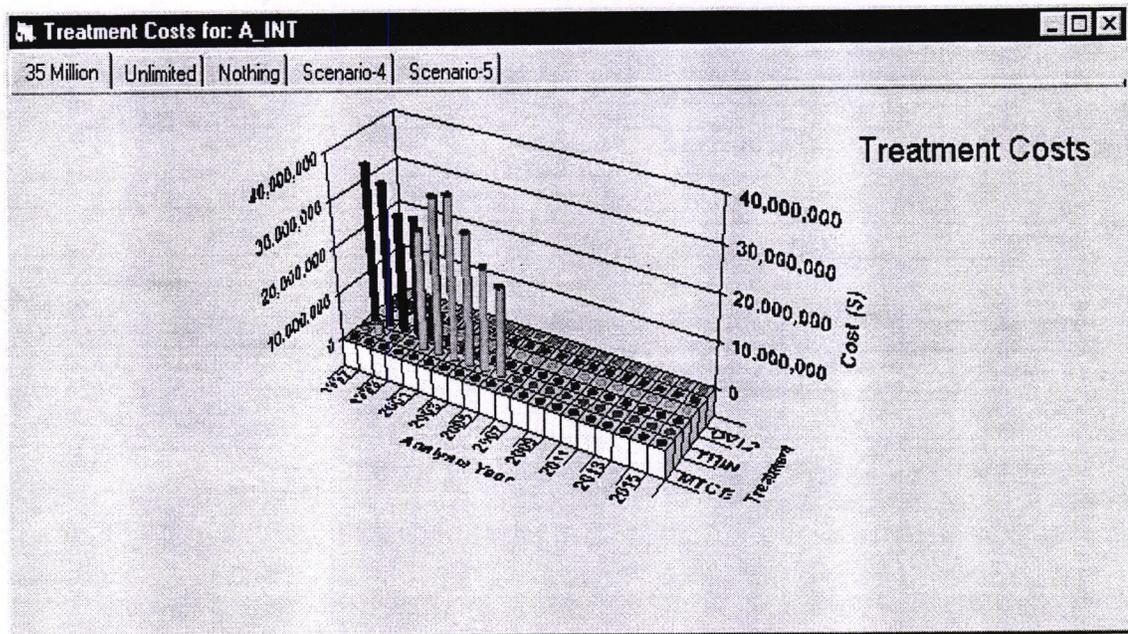


Figure 9 – Sample Analysis Treatment Cost Graph

CONTINUED DEVELOPMENT/IMPLEMENTATION

Continued Data Collection

To improve the PMS in the future, consistent data collection is required. A central location for all databases or one large database would be helpful. A larger historical database will allow for more accurate segmentation.

Redefined Performance Curves

After a few more years of continued data collection, new or more specific performance curves may be developed. More specific performance curves will more accurately predict the future condition of Arkansas' pavements and eventually this network level PMS may be also useful at the project level.

In addition, the ability to customize the performance curves to individual sections will provide a more robust tool for the AHTD to conduct site-specific performance prediction. This ability will become even more important when the AHTD actually relies on the results from the PMS for decision-making in the future.

Additional Distresses / Performance Indices

Another future development can be the addition of new distresses or performance indices. For instance, distress data, such as cracking, faulting, etc., is an important property of a pavement section and an integral part of a useful Pavement Management System. Also, surface friction may be a desired performance index.

Additional Treatments

Additional treatments may also be implemented in the future. Other types of treatments provide for more strategies and therefore more options to be considered. With many treatments or strategies to consider, dTIMS® can better determine the optimal set of strategies to apply to the network. This could save the AHTD money and time in the long run.

More Pavement Types

Future data collection should consider more pavement types to broaden the details of analysis. For instance, the following pavement types may be included for future data collection:

Flexible Pavement: with stabilized base, with granular base, and full depth;

Rigid pavements: CRCP, non-reinforced, base type, with drainage, without drainage.

CONCLUSION

In this project, the Interstate and NHS routes were segmented using historical data from the AHTD. Performance curves were developed for different pavement types from available historical condition data. Thereafter, dTIMS® was set up initially and sample analyses were performed using the performance curves. This calibration of dTIMS® should only be considered as a first step towards a complete Pavement Management System. In the study, a limited amount of historical data was available to generate the performance curves. The limited historical data and the grouping of sections with similar characteristics (e.g. age, pavement thickness, and traffic volumes) provided sufficient data to develop performance curves. However, after a treatment (e.g. thin overlay, thick overlay, CPR) was applied to a specific section, and the performance indices were reset, that section did not deteriorate to the point of needing a second treatment within the 20-year time frame used in this analysis. Additional development of the performance curves will be required before dTIMS® can be implemented by the AHTD.

Performance curves for rutting were developed for both Interstate and NHS pavements. However, due to the unpredictable nature of rutting, these performance curves are not used in dTIMS® for analysis at this time

It is recommended that AHTD consolidate the PMS related databases, so that any data from the databases can be readily obtained. These databases include structural, traffic, geometric, and data sets collected with the data vehicle. After additional data collection for several more years, better predictions of various pavement types' performances may be developed with both currently available data and the newly collected data.

Construction Programme for: A_INT -> 35 Million										
2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	
1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	
Element ID	First Treatment Type	First Treatment Cost (\$)	First Trt Budget Category	Second Treatment Type	Second Treatment Year	Second Treatment Cost (\$)	2nd Trt Budget Category	Present Value Costs (\$/mi)	Present Value Benefits/mi	
▶ 302311319	THIN	1,214,820	INTS					300,000	54,227,139.5	
302321319	THIN	1,205,640	INTS					300,000	52,734,122.4	
302311369	THIN	612,000	INTS					300,000	08,676,816.6	
402210943	THIN	2,493,900	INTS					300,000	35,379,836.5	
403111025	THIN	1,854,360	INTS					300,000	36,823,155.9	
403121025	THIN	1,854,360	INTS					300,000	36,815,284.3	
403111085	THIN	1,340,280	INTS					300,000	37,970,925.2	
403121085	THIN	1,340,280	INTS					300,000	37,970,925.2	
403111129	THIN	2,255,220	INTS					300,000	38,320,571.8	
403121129	THIN	2,255,220	INTS					300,000	38,327,245.6	
403211238	THIN	1,787,040	INTS					300,000	43,273,478.4	
403221238	THIN	1,787,040	INTS					300,000	43,430,426.1	
403211296	THIN	2,692,800	INTS					300,000	44,986,749.9	
403221296	THIN	2,692,800	INTS					300,000	45,044,446.4	

Figure 10– Sample Analysis Construction Program

Problems and Solutions

Cumulative ESAL Reset

One of the restrictions in dTIMS® is the cumulative ESAL reset. When a treatment is applied to an element, that element’s cumulative ESAL is reset. Since all performance curves are based on cumulative ESAL’s, this causes all performance curves to start over. This is necessary for some of the performance curves but might not be for others. For instance, a treatment may be applied because of a certain low performance data field rating, however, that treatment may not correct the problems causing other low performance data field ratings. This is why only thin overlay and thick overlay are used for interstate pavements and only structural overlay for non-interstate NHS pavements.

The variable GCUMESAL used in the performance curves is a runtime variable and is calculated internally by dTIMS®. To correct the above problem, separate cumulative ESAL’s can be created for each performance curve. These cumulative ESAL’s will be performance data fields themselves and will grow or deteriorate over time through corresponding performance curves. In addition, when each performance curve has its own independent method to obtain its ESAL values, the performance fields should be chosen as relative indices. That means that the new calculated value will be added to the previous year’s value, making it cumulative. The approach illustrated in this paragraph is not implemented.

(Note: The manual describes a checkbox located in the performance index property window, which lets the user choose the index as a relative index. However, the program and the 'Help' manual in the program do not include this checkbox. Instead, a checkbox describing whether or not to use curve shifting is used and described.)

Treatments

Once the cumulative ESAL problem is solved, different treatments may be added to the system. Treatments such as Concrete Patching and Restoration (CPR), which has its own performance curve, could be applied. This treatment corrects structural problems but does not correct and sometimes worsens roughness. New types of treatments with different costs, resets, treatment times, etc. provide many new strategies to consider and will improve the usefulness of the PMS.

REFERENCES

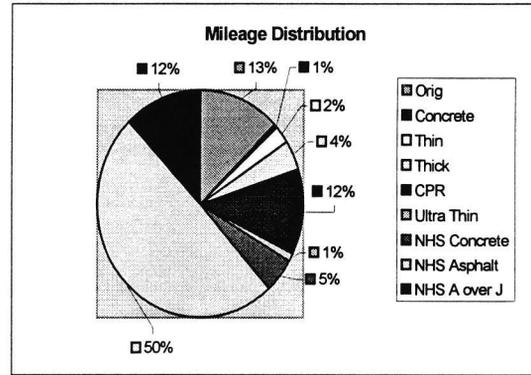
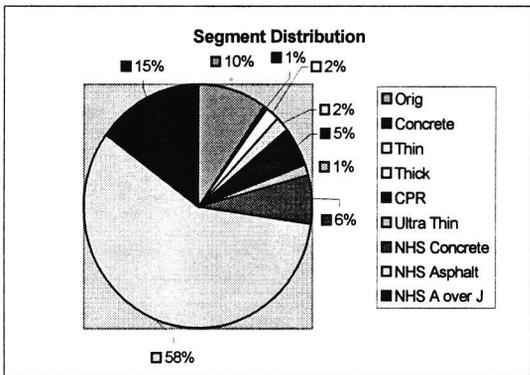
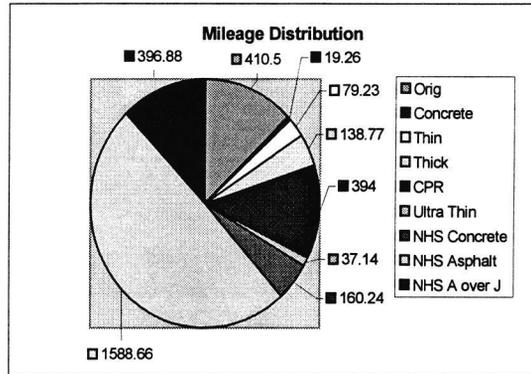
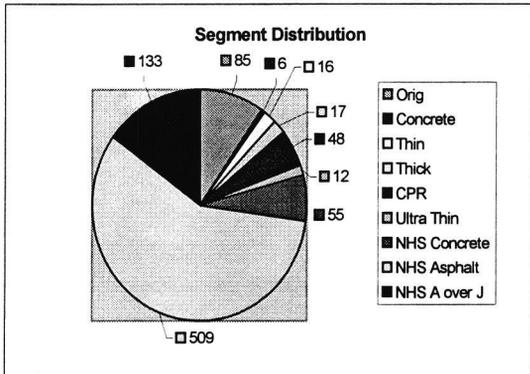
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Appendix A

Segment Distribution

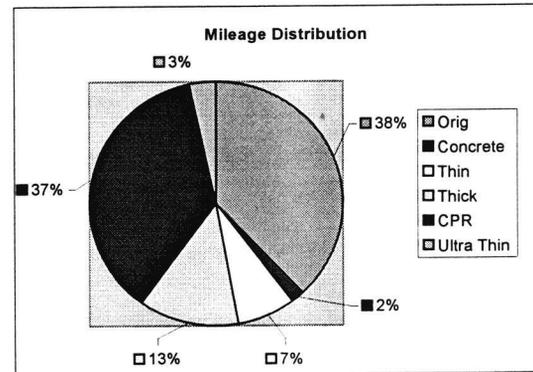
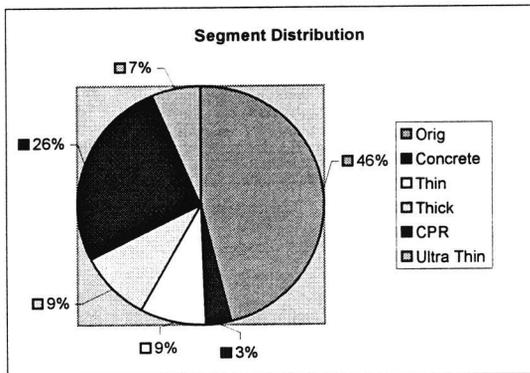
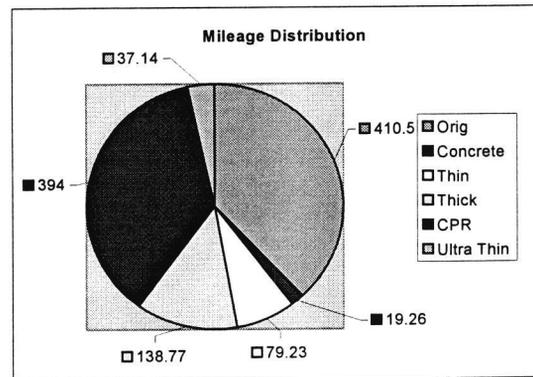
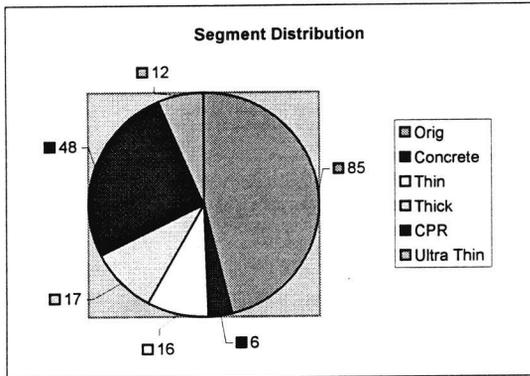
Segment Distribution (Entire Network)

Pavement Group	Number of Segments	% of Segments	Number of Miles	% of Miles	Avg. Length per Segment
Orig	85	9.65%	410.5	12.73%	4.83
Concrete	6	0.68%	19.26	0.60%	3.21
Thin	16	1.82%	79.23	2.46%	4.95
Thick	17	1.93%	138.77	4.30%	8.16
CPR	48	5.45%	394	12.22%	8.21
Ultra Thin	12	1.36%	37.14	1.15%	3.10
NHS Concrete	55	6.24%	160.24	4.97%	2.91
NHS Asphalt	509	57.78%	1588.66	49.27%	3.12
NHS A over J	133	15.10%	396.88	12.31%	2.98



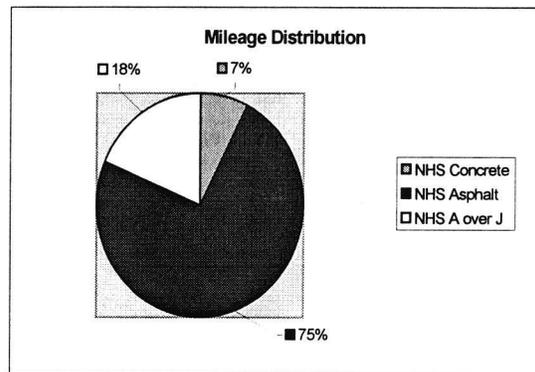
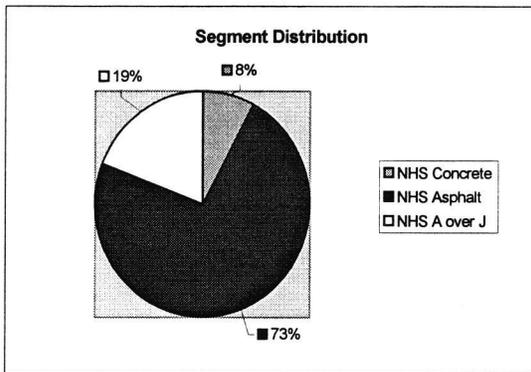
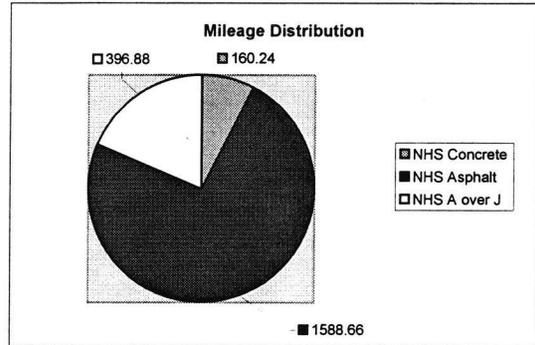
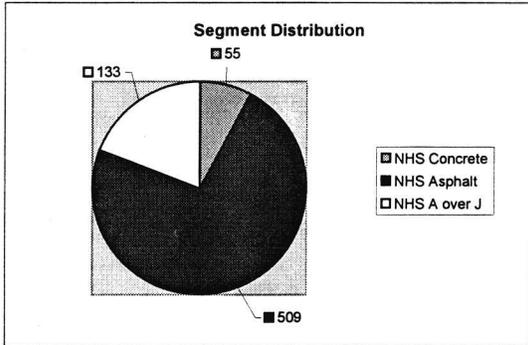
Segment Distribution (Interstate)

Pavement Group	Number of Segments	% of Segments	Number of Miles	% of Miles	Avg. Length per Segment
Orig	85	46.20%	410.5	38.05%	4.83
Concrete	6	3.26%	19.26	1.79%	3.21
Thin	16	8.70%	79.23	7.34%	4.95
Thick	17	9.24%	138.77	12.86%	8.16
CPR	48	26.09%	394	36.52%	8.21
Ultra Thin	12	6.52%	37.14	3.44%	3.10



Segment Distribution (Non-Interstate NHS)

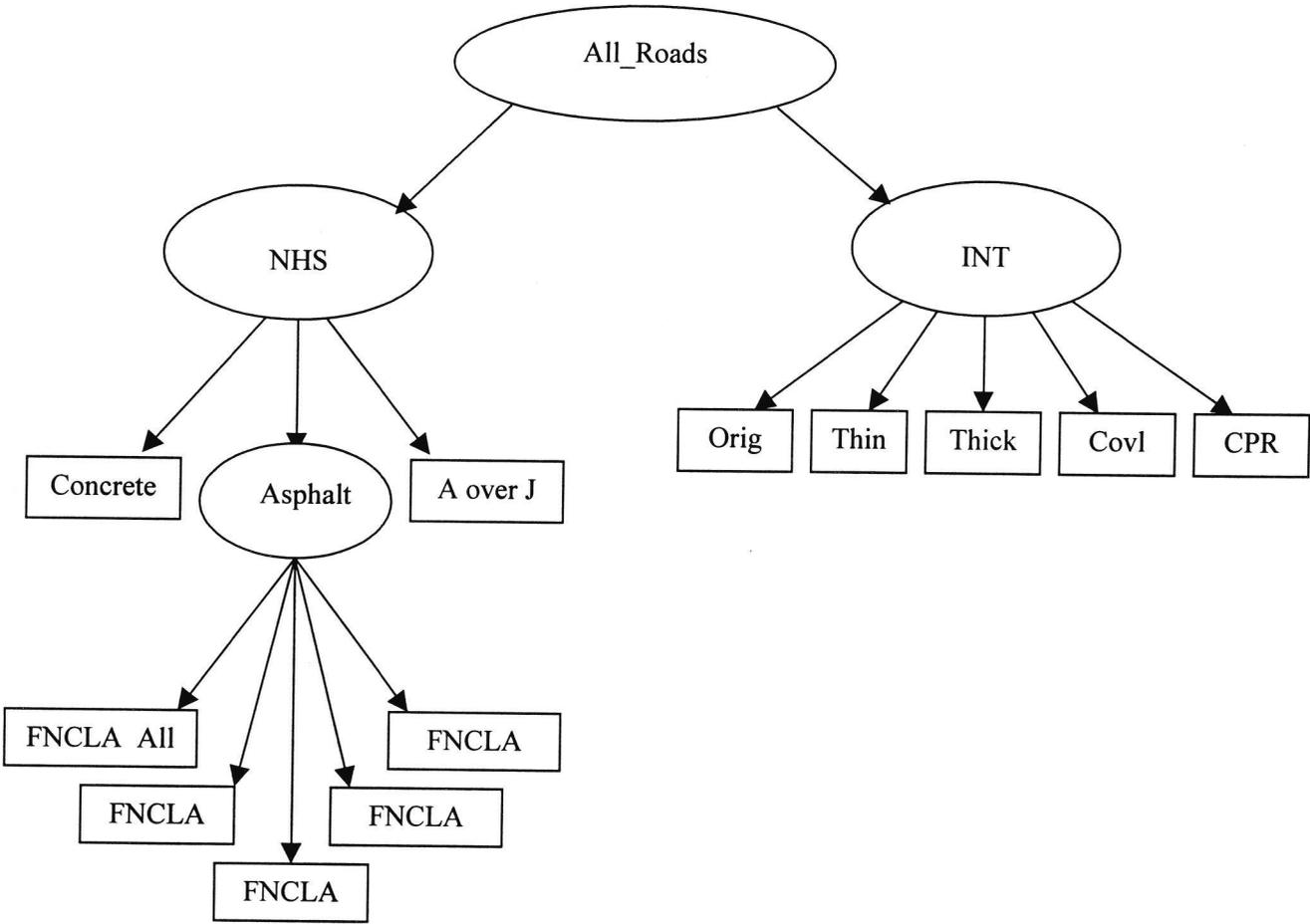
Pavement Group	Number of Segments	% of Segments	Number of Miles	% of Miles	Avg. Length per Segment
NHS Concrete	55	7.89%	160.24	7.47%	2.91
NHS Asphalt	509	73.03%	1588.66	74.04%	3.12
NHS A over J	133	19.08%	396.88	18.50%	2.98



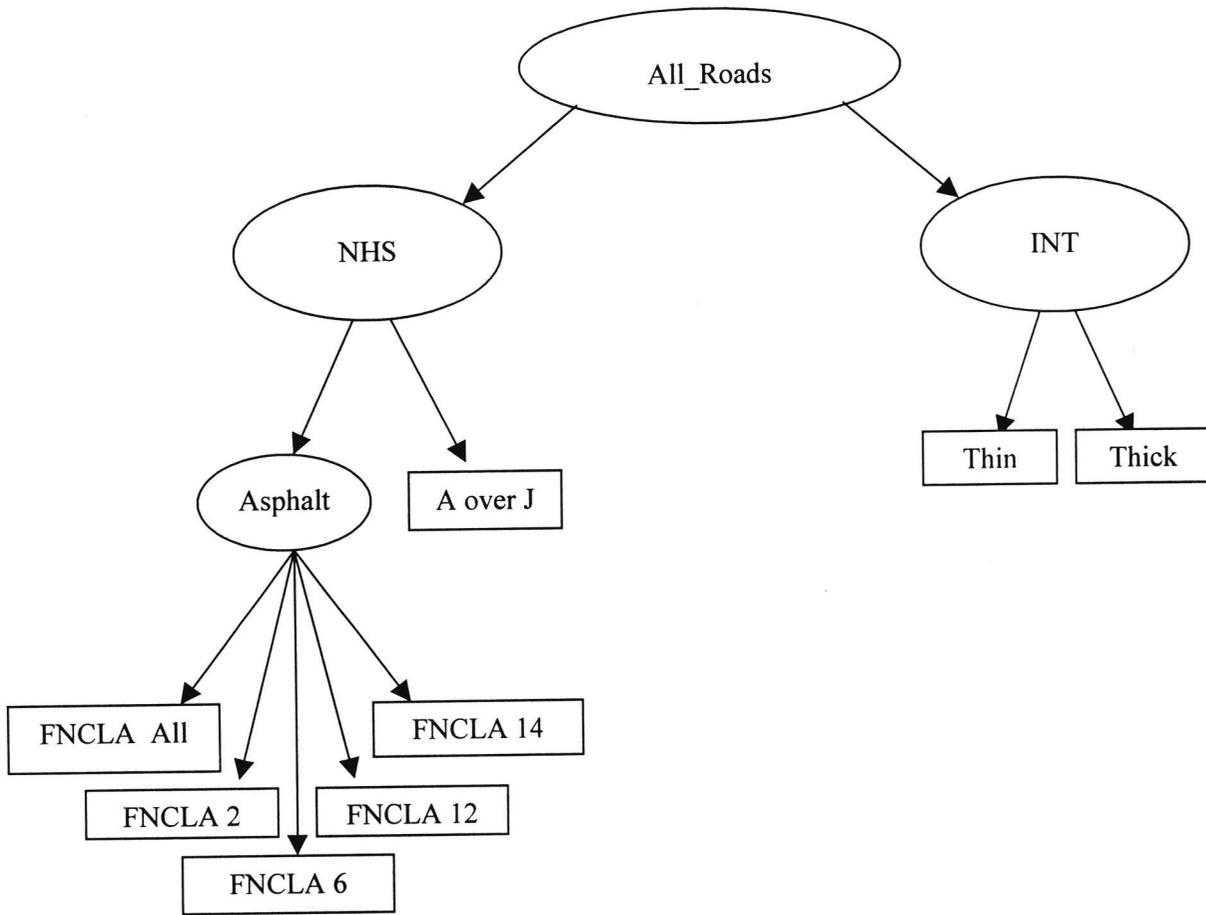
Appendix B

Performance Curve Decision Trees

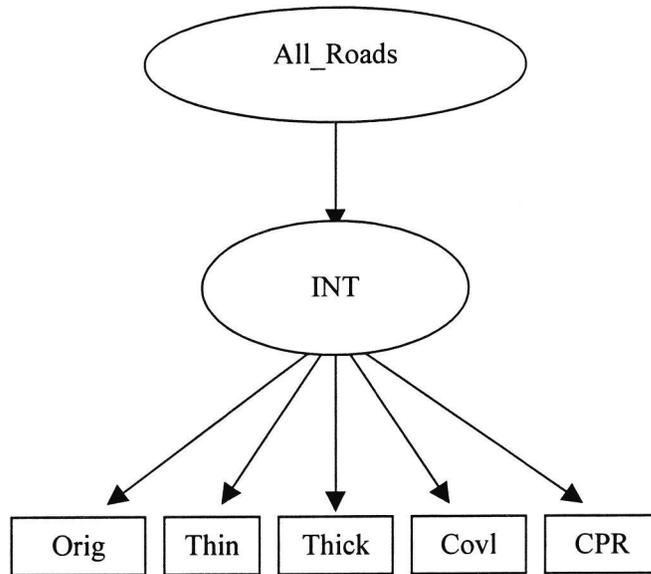
IRI Performance Curve Decision Tree



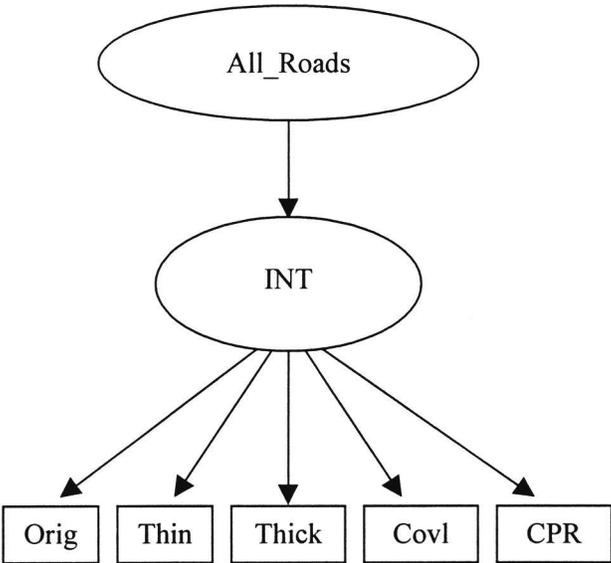
Rut Performance Curve Decision Tree



RRI Performance Curve Decision Tree



SRI Performance Curve Decision Tree



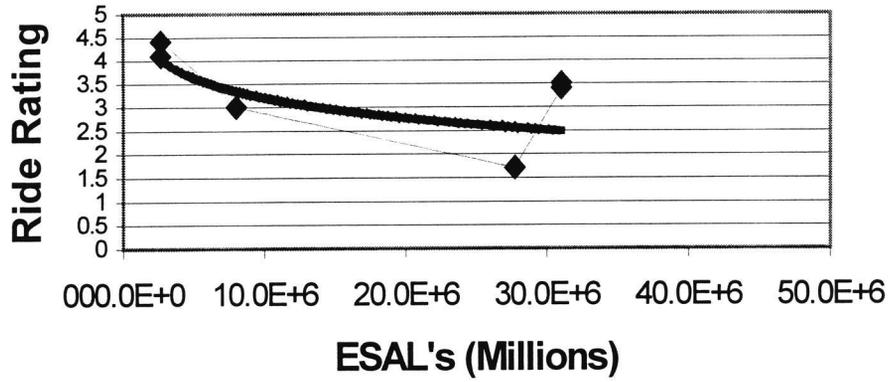
Appendix C

Performance Curve Plots & Formulas

Concrete Overlay

$$y = -0.6292\ln(x) + 13.338$$

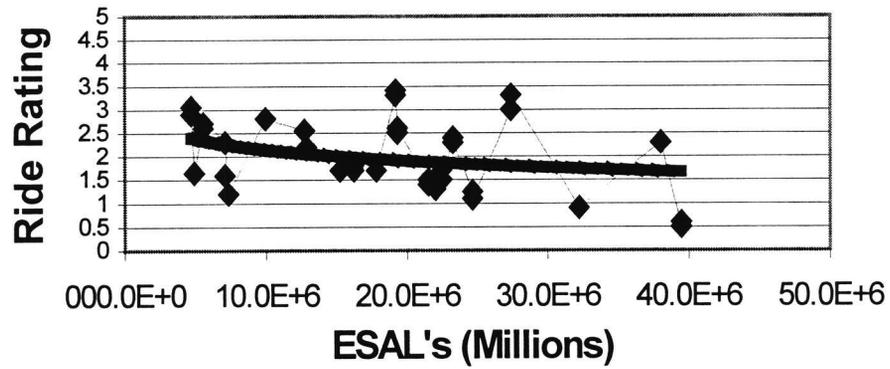
$$R^2 = 0.4621$$



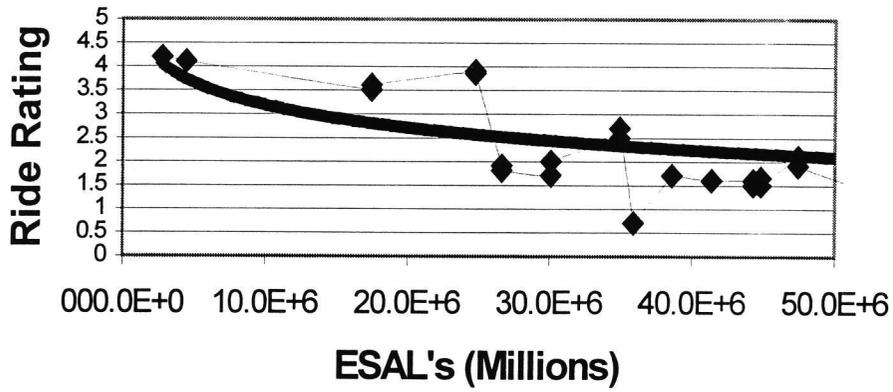
CPR

$$y = -0.3465\ln(x) + 7.7269$$

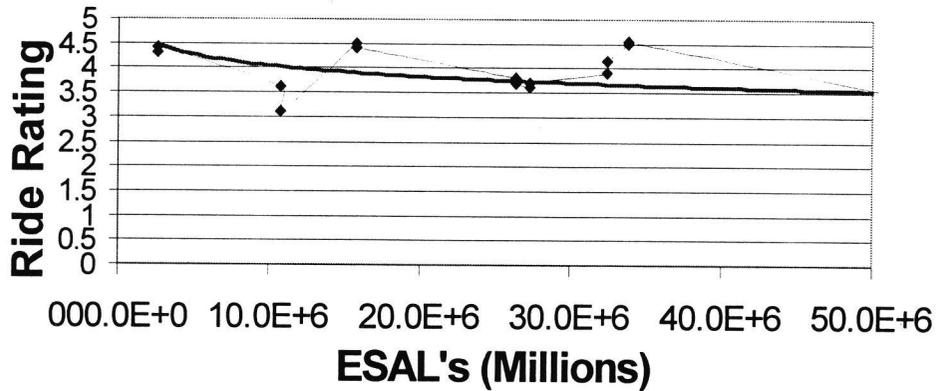
$$R^2 = 0.0851$$

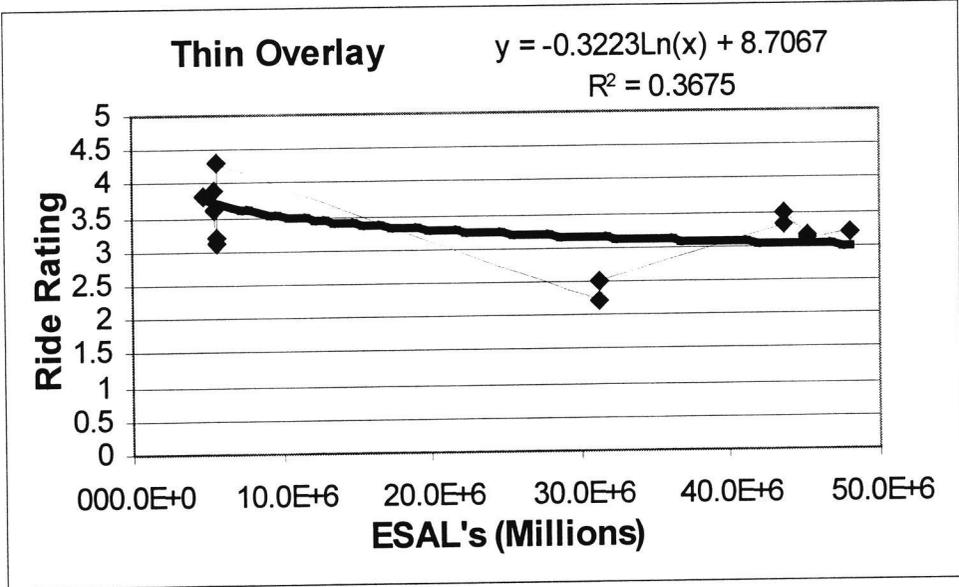


Original/Reconstruction $y = -0.6783\ln(x) + 14.113$
 $R^2 = 0.4317$



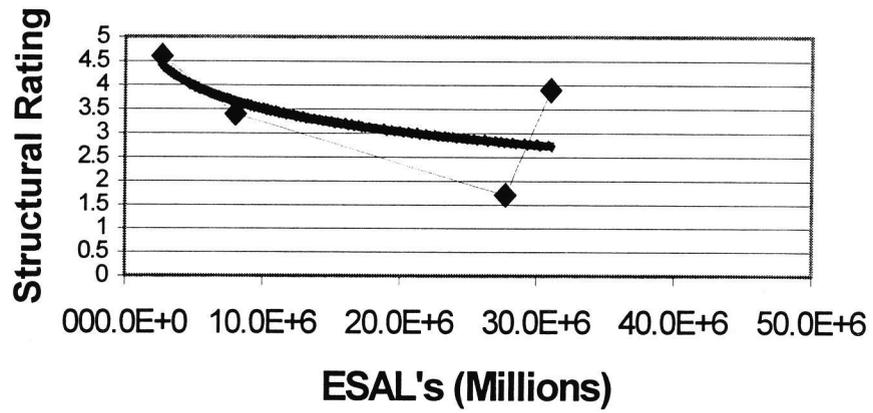
Thick Overlay $y = -0.3108\ln(x) + 9.0478$
 $R^2 = 0.2338$





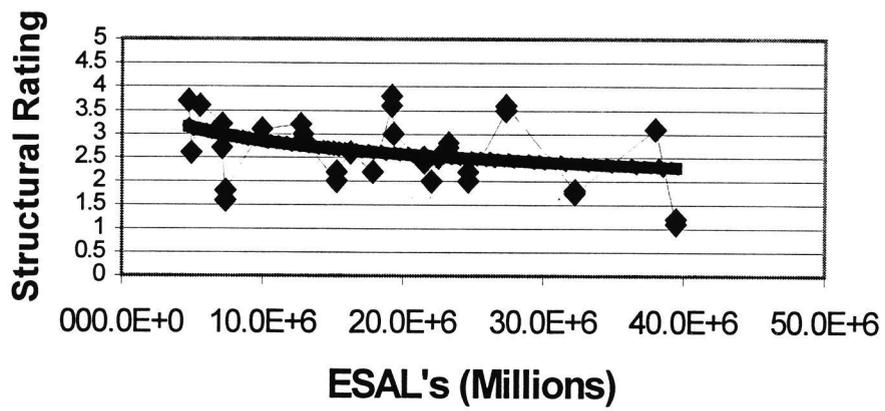
Concrete Overlay

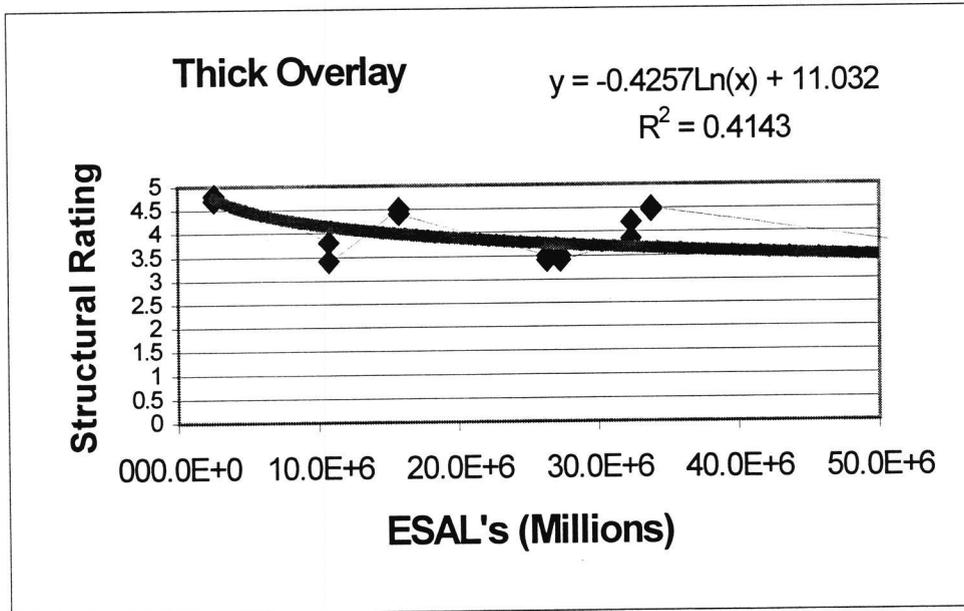
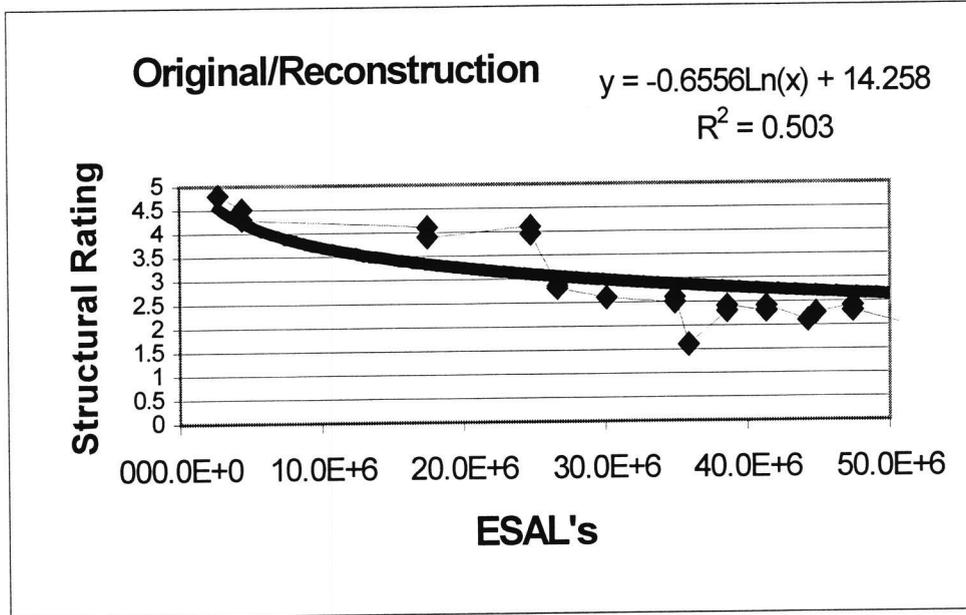
$$y = -0.6851\ln(x) + 14.548$$
$$R^2 = 0.4115$$



CPR

$$y = -0.4071\ln(x) + 9.4109$$
$$R^2 = 0.139$$

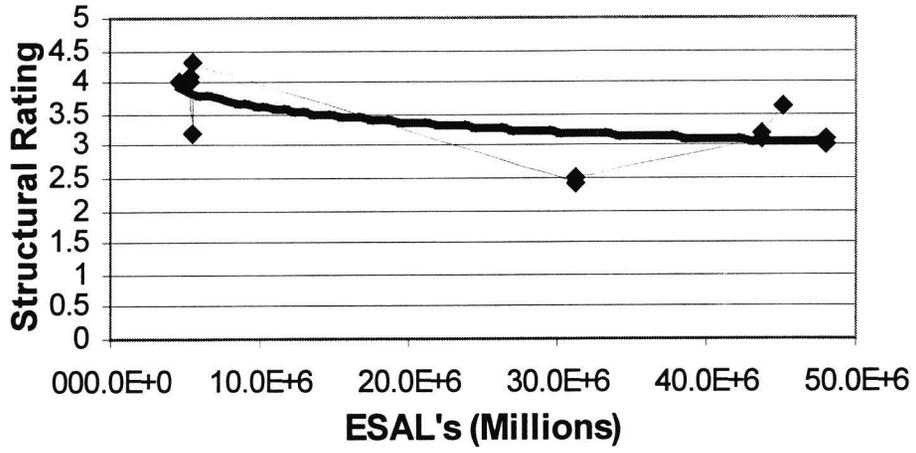


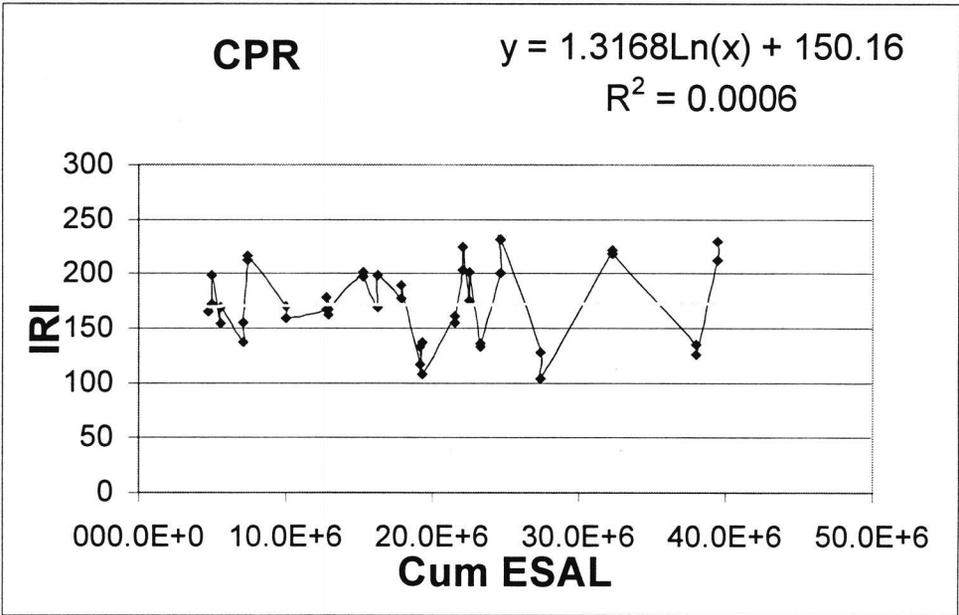
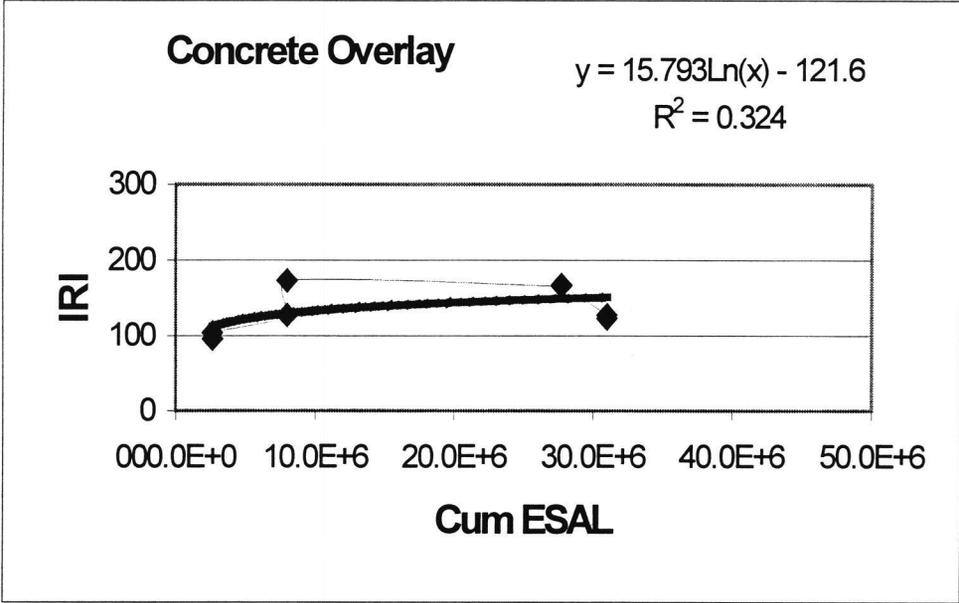


Thin Overlay

$$y = -0.3718\ln(x) + 9.615$$

$$R^2 = 0.436$$

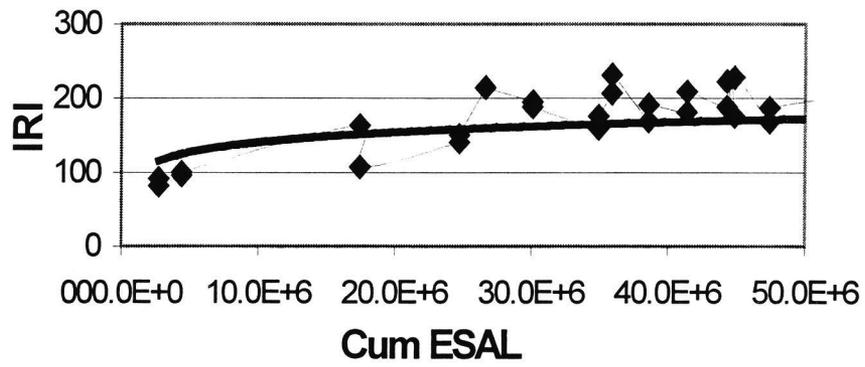




Original/Reconstruction

$$y = 19.747\ln(x) - 177.91$$

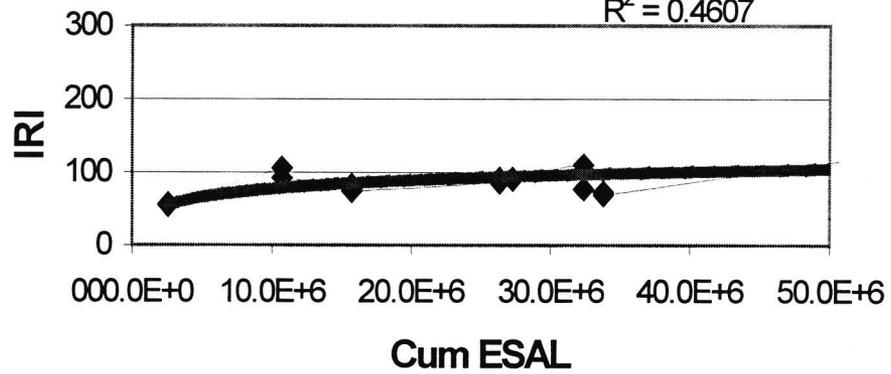
$$R^2 = 0.1969$$



Thick Overlay

$$y = 16.798\ln(x) - 193.66$$

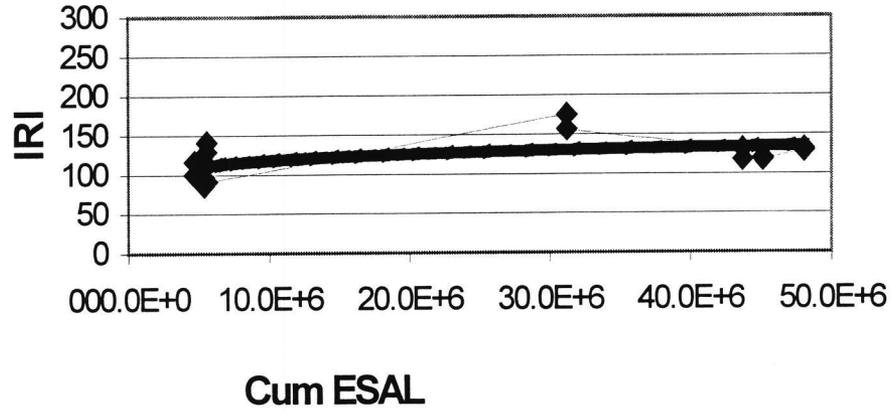
$$R^2 = 0.4607$$



Thin Overlay

$$y = 11.143\ln(x) - 62.062$$

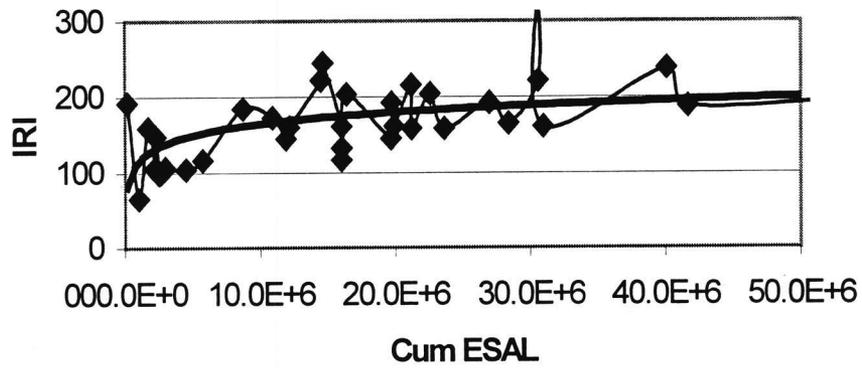
$$R^2 = 0.2605$$

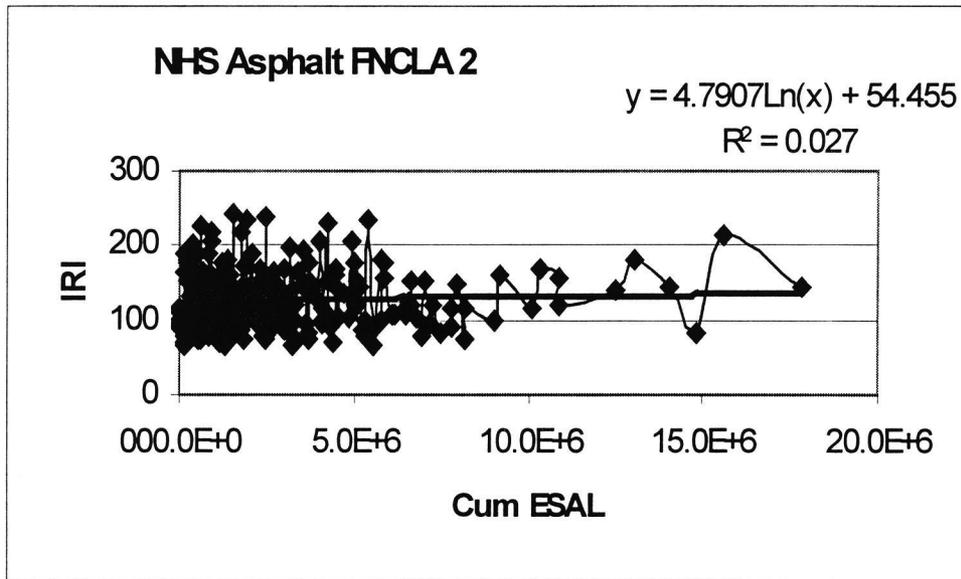
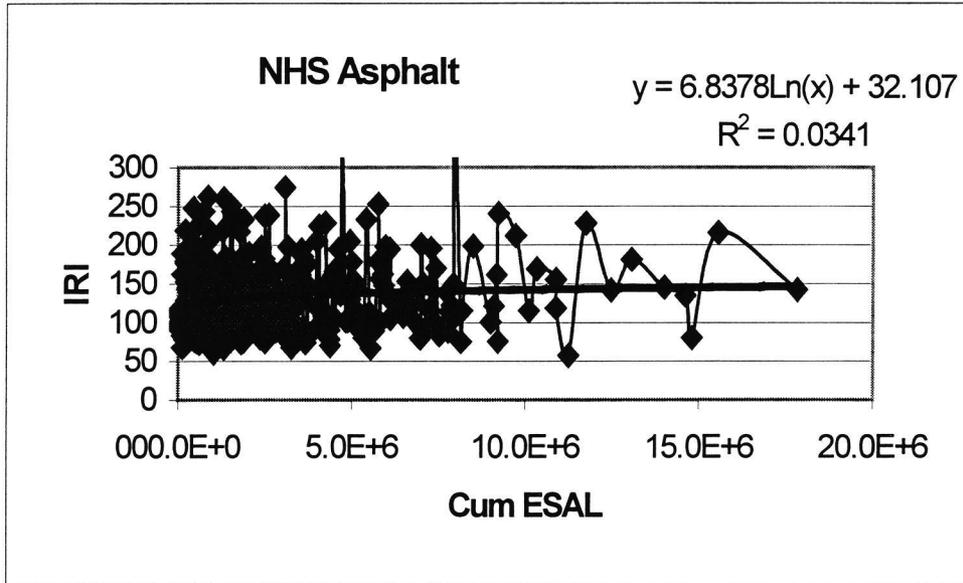


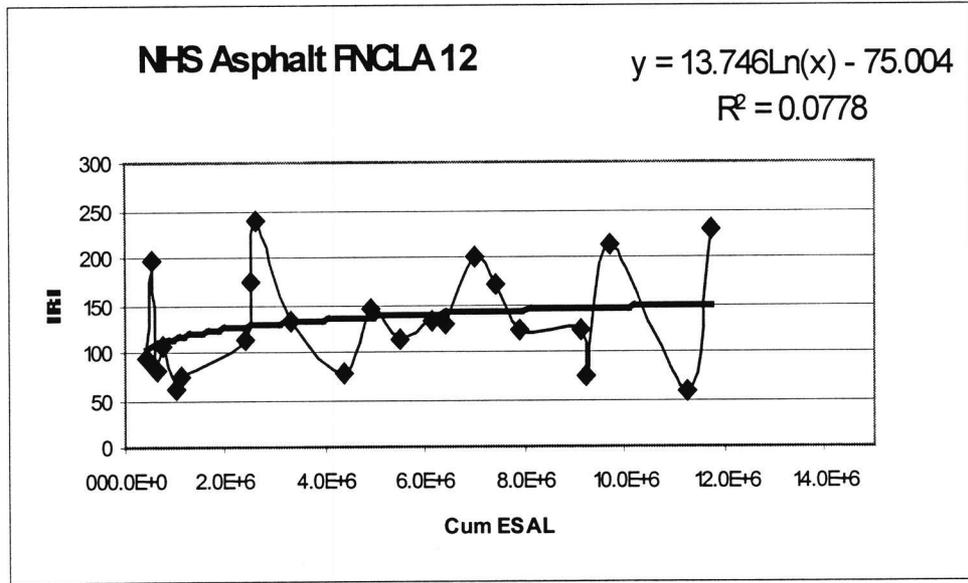
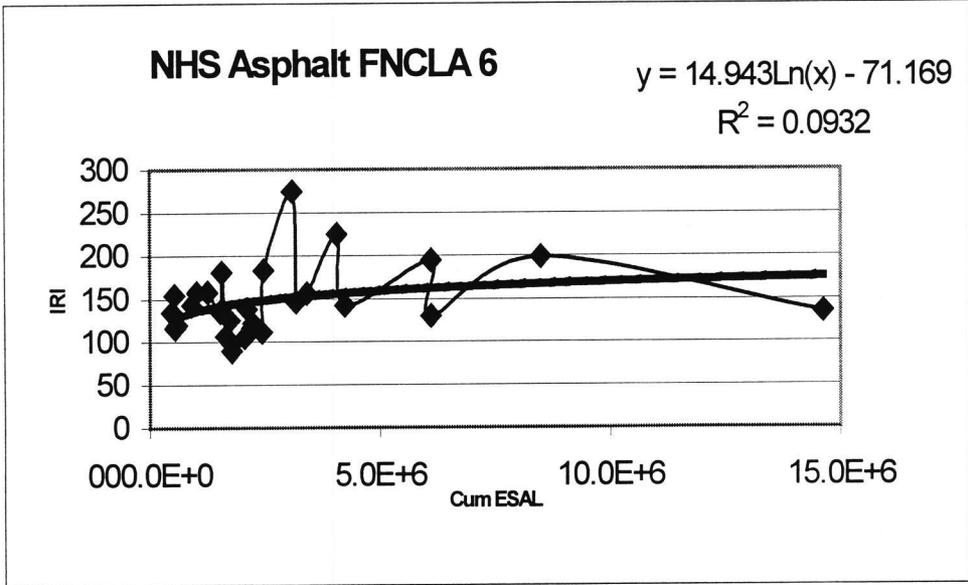
NHS Concrete

$$y = 22.038\ln(x) - 190.96$$

$$R^2 = 0.3141$$



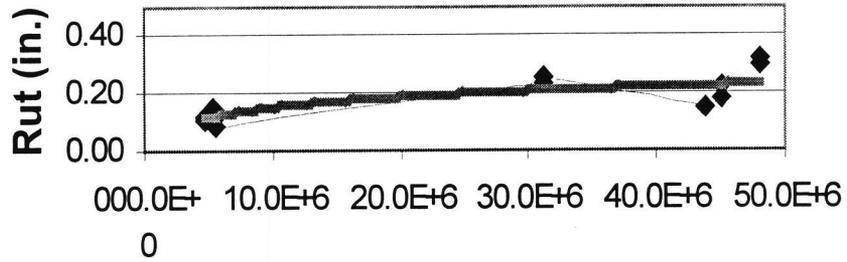




Thin Overlay

$$y = 0.051\ln(x) - 0.6708$$

$$R^2 = 0.5893$$

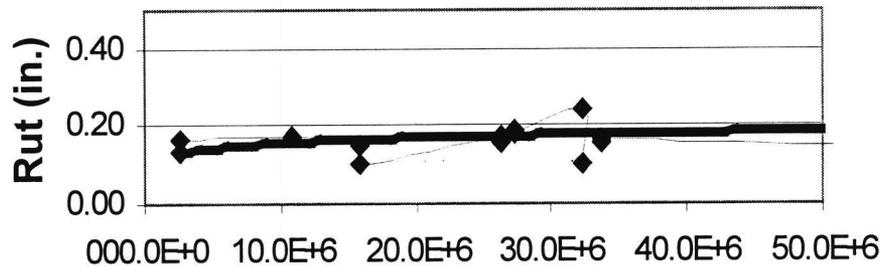


CumESAL

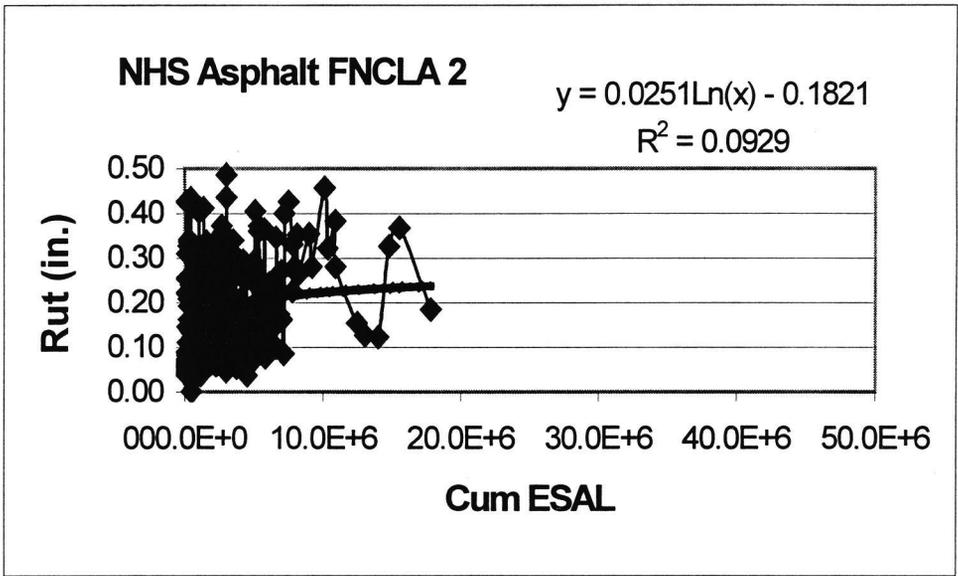
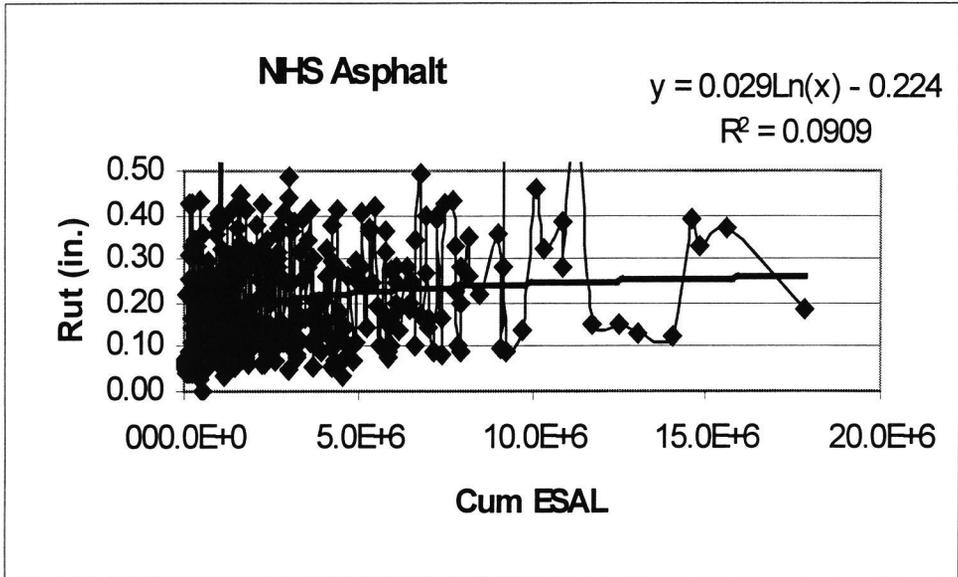
Thick Overlay

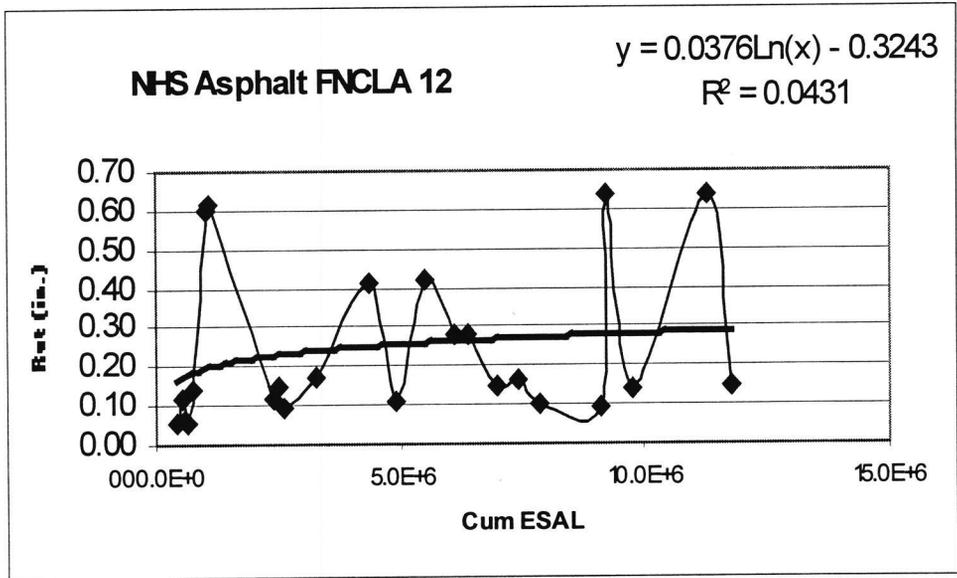
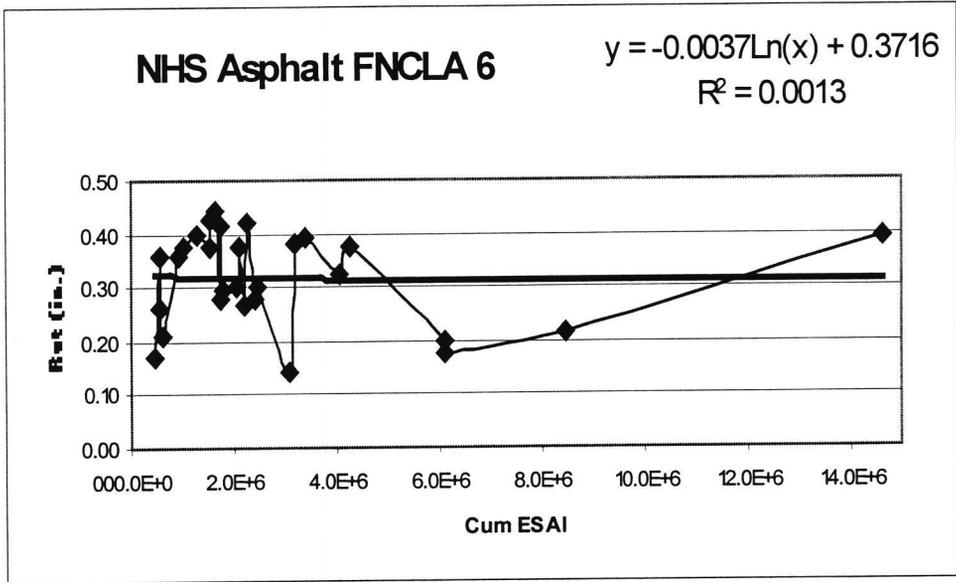
$$y = 0.0187\ln(x) - 0.1457$$

$$R^2 = 0.1693$$



CumESAL

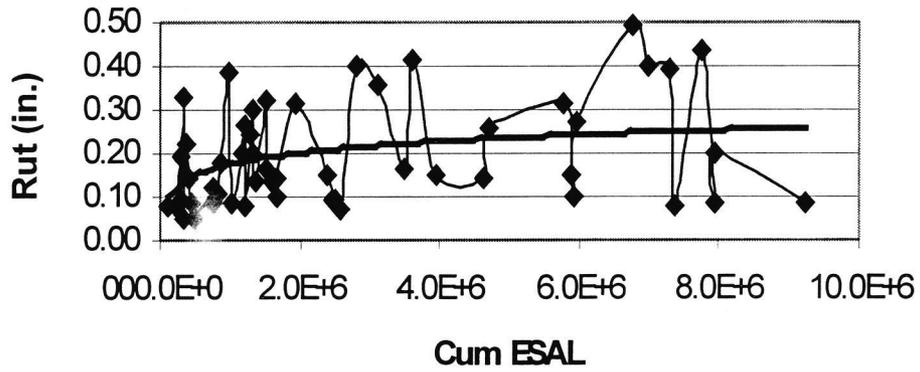




NHS Asphalt FNCLA 14

$$y = 0.0373\ln(x) - 0.3401$$

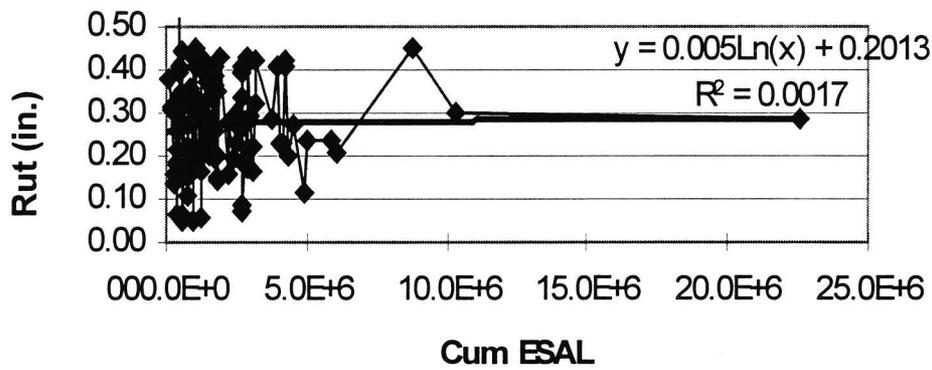
$$R^2 = 0.1207$$



NHS Asphalt over Jointed Concrete

$$y = 0.005\ln(x) + 0.2013$$

$$R^2 = 0.0017$$



Appendix D

AHTD Inventory Database



FESECTI	FLENCTI	FNAME	FOFFER	FOFFETO	FODESCR	ADDT	CLIM E	AXLEO	LRSPLI	COM T	COM C	COM Y	COM B	TRAV	PCT C	YR	LR	LSIN	FI	DSTNO	CONTY	SECTN	LAWID	ENCLA	YRADT	SURTY	LFASYS	SURF C	IRI	RUT	SRL	RR	REH TY
4031110	438		10854	11292		31908	4883149	1.542	1	1				36	19	1988						31	12					188	0	2.1	1.5	Ora	
4031111	438		10854	11292		31908	4883149	1.542	1	1				36	18	1988						31	12					176	0	2.25	1.5	Ora	
4031112	737		11292	20229		32122	4843385	1.542	1	1				36	18	1988						31	12					228	0	0	0	Ora	
4000112	347		10258	12376		32122	5943585	1.542	1	1				36	18	1988						31	12					187	0	0	0	Ora	
4032112	584		12376	12360		32512	5252237	1.542	1	1				36	18	1987						32	12					247	0	0	0	Ora	
4032112	584		12376	12360		32744	2486206	1.542	1	1				36	18	1987						32	12					175	0	2.3	1.5	CPR	
4032112	880		12360	13840		33107	2736228	1.542	1	1				36	18	1987						32	12					200	0	2.2	1.25	CPR	
4000113	838		13840	14676		33107	6735223	1.542	1	1				36	17	1986						32	12					232	0	2	1.1	CPR	
4033114	528		14676	15202		33819	6732037	1.542	1	1				36	17	1986						32	12					193	0	0	0	Ora	
4033214	528		14676	15202		34238	7123277	1.542	1	1				36	16	1984						33	12					230	0	0	0	Ora	
4033115	67		15202	15269		34238	7123277	1.542	1	1				36	16	1984						33	12					172	0	1.1	1.9	Ora	
4033215	67		15202	15269		36787	1027401	1.542	1	1				36	18	1983						33	12					243	0	1.7	1.7	Ora	
4033115	182		15269	1658		36787	1027401	1.542	1	1				36	18	1983						33	12					253	0	1.7	1.7	Ora	
4033115	182		15269	1658		34355	3084558	1.542	1	1				36	20	1988						33	12					127	0	3.9	3.4	Concret	
4033115	831		16580	15550		34355	3084558	1.542	1	1				36	20	1988						33	12					123	0	3.8	3.5	Concret	
4033215	831		16580	15550		32328	1400853	1.542	1	1				36	21	1983						33	12					197	0	3.2	2.55	CPR	
4041116	1113		17484	17494		26782	101E+0	1.542	1	1				36	29	1984						33	12					150	0	2.7	2.3	Ora	
4041117	348		17494	17494		23373	9694711	1.542	1	1				36	38	1965						41	12					150	0	2.7	2.1	Ora	
4041117	715		17494	18555		23373	9694711	1.542	1	1				36	38	1965						41	12					152	0	2.5	2.0	Ora	
4041217	715		17840	18555		23657	2566079	1.542	1	1				36	38	1991						41	12					182	0	2.5	1.8	Ora	
4042218	781		18555	18946		23657	2566079	1.542	1	1				36	38	1991						41	12					133	0	2.2	2.4	CPR	
4042218	781		18555	18946		24381	4189834	1.542	1	1				36	40	1987						41	12					135	0	3.1	2.3	CPR	
4042119	510		18946	19858		24921	9129024	1.542	1	1				36	42	1987						42	12					128	0	3.1	2.3	CPR	
4042119	275		19858	20131		24921	9129024	1.542	1	1				36	42	1987						42	12					146	0	2.7	2.2	Ora	
4042120	344		20131	20475		25364	8947305	1.542	1	1				36	44	1968						42	12					146	0	2.6	1.9	Ora	
4042120	344		20131	20475		25364	8947305	1.542	1	1				36	44	1968						42	12					165	0	2.6	2.3	Ora	
4042220	344		20475	20530		25505	8226640	1.542	1	1				36	44	1966						42	12					181	0	2.9	2.2	Ora	
4042220	55		20530	20530		25777	8919915	1.542	1	1				36	45	1968						42	12					129	0	2.9	2.2	Ora	
4042220	380		20530	20910		25777	8919915	1.542	1	1				36	45	1968						42	12					137	0	2.9	2.3	Ora	
4042220	380		20530	20910		25777	5943455	1.025	1	1				36	45	1966						42	12					89	0	4.1	3.8	Thin	
4042120	309		20910	21218		25777	5943455	1.025	1	1				36	45	1966						42	12					137	0	2.4	1.8	Ora	
4042120	309		20910	21218		26037	8897089	1.542	1	1				36	46	1968						42	12					154	0	2.3	1.6	Ora	
4042120	309		21218	21440		26037	8897089	1.542	1	1				36	46	1968						42	12					188	0	2.2	1.5	Ora	
4043221	921		21440	22140		26225	8883384	1.542	1	1				36	47	1968						43	12					188	0	2.2	1.5	Ora	
4051122	1512		22140	23652		26225	8883384	1.542	1	1				36	47	1968						43	12					188	0	2.55	2.15	Ora	
4051122	1512		22140	23652		26225	8883384	1.542	1	1				36	47	1968						43	12					153	0	2.8	1.9	Ora	
4051123	321		23652	23973		26173	9176942	1.542	1	1				36	48	1968						51	12					184	0	2.6	1.9	Ora	
4051123	321		23652	23973		26173	9176942	1.542	1	1				36	48	1968						51	12					184	0	2.2	1.7	Ora	
4051123	265		23973	24228		26202	101E+0	1.542	1	1				36	48	1968						51	12					188	0	2.55	2.15	Ora	
4051123	265		23973	24228		24948	6243456	1.025	1	1				36	49	1968						51	12					184	0	2.8	1.9	Ora	
4051124	582		24228	24810		24948	6243456	1.025	1	1				36	49	1968						51	12					112	0.11632	4.3	4.3	Thin	
4051124	582		24228	24810		24778	1758901	1.025	1	1				36	49	1996						51	12					91	0.09861	4.3	4.3	Thin	
4051124	1847		24810	26457		24778	1758901	1.025	1	1				36	49	1994						51	12					74	0.10088	4.3	4.4	Thick	
4052126	157		26457	26509		24268	3815760	1.025	1	1				36	49	1960						51	12					109	0.24394	3.85	3.9	Thick	
4052126	157		26457	26509		22807	8262181	1.542	1	1				36	48	1968						51	12					77	0.10094	4.2	4.15	Thick	
4052226	436		26509	26509		22807	8262181	1.542	1	1				36	48	1968						52	12					128	0	3	2.8	Ora	
4000226	436		26509	26945		22807	8262181	1.542	1	1				36	48	1968						52	12					119	0	3	2.8	Ora	
4052126	848		26945	27153		22807	8262181	1.542	1	1				36	48	1968						52	12					140	0	0	0	Ora	
4052126	848		26945	27153		22807	8262181	1.542	1	1				36	48	1968						52	12					172	0	0	0	Ora	
4052127	170		27153	27963		22860	5517841	1.542	1	1				36	48	1966						52	12					172	0	2.6	1.65	CPR	
4052227	170		27963	27963		21673	1951041	1.542	1	1				36	48	1963						52	12					198	0	2.6	1.65	CPR	
4052227	117		27963	28080		21697	7430631	1.542	1	1				36	48	1963						52	12					163	0	4.1	3.5	Ora	
4052227	117		27963	28080		21697	7430631	1.542	1	1				36	48	1963						52	12					107	0	3.9	3.8	Ora	
4052228	89		28080	28178		21697	7430631	1.025	1	1				36	48	1968						52	12					184	0	2.9	2.4	Ora	
4052228	290		28178	28469		21697	7430631	1.025	1	1				36	48	1968						52	12					116	0.10457	4	3.8	Thin	
4052228	290		28178	28469		2																											

F.SECT.	F.IENGT	F.NAME	F.OFFER	F.OFFT	F.DESCF	F.DESCT	AADT	CLUM_E	TAXEQ	LRSPILI	COM.T	COM.Y	COM.B	TRAV	PCT.C	YR.LST	ISINELT	DSTNO.	CONTY	SECTN	LAWID	ENCL	VRADT	SURTY	FASYS	SUBR	C	JRI	RUT	SRL	RRI	REH.TV
4903101	122	49	199	1321			2500	138457	0.725	0.6				51	12	1973		10	18	3	12	1996	65	2	2	231.865	0.13468	0	0	N/A		
4903101	122	49	199	1321			2500	138457	0.725	0.6				51	12	1973		10	18	3	12	1996	65	2	2	231.865	0.13468	0	0	N/A		
4903101	176	49	176	854			9805	4984212	0.85	0.6				50	16	1984		1	48	8	12	1996	65	2	2	138.501	0.11569	0	0	N/A		
4903101	176	49	176	854			9805	4984212	0.85	0.6				50	16	1984		1	48	8	12	1996	65	2	2	138.501	0.11569	0	0	N/A		
4909101	1200	49	113	1313			1863	3415847	0.85	0.6				24	18	1982		1	48	9	12	1996	63	2	2	102.237	0.04689	0	0	N/A		
4909101	1200	49	113	1313			1863	3415847	0.85	0.6				24	18	1982		1	48	9	12	1996	63	2	2	102.237	0.04689	0	0	N/A		
4909101	879	49	1313	2192			2050	953563	0.85	0.6				24	18	1982		1	48	9	12	1996	63	2	2	102.237	0.04689	0	0	N/A		
4909101	879	49	1313	2192			2050	953563	0.85	0.6				24	18	1982		1	48	9	12	1996	63	2	2	102.237	0.04689	0	0	N/A		
4910100	500	49	500	481			5400	1694979	0.85	0.6				22	18	1980		1	54	10	11	1996	65	2	2	80.5800	0.07415	0	0	N/A		
4910100	500	49	500	481			5400	1694979	0.85	0.6				22	18	1980		1	54	10	11	1996	65	2	2	80.5800	0.07415	0	0	N/A		
4910100	313	49	800	813			5400	1694979	0.85	0.6				22	18	1980		1	54	10	11	1996	65	2	2	80.5800	0.07415	0	0	N/A		
4910100	313	49	800	813			5400	1694979	0.85	0.6				22	18	1980		1	54	10	11	1996	65	2	2	80.5800	0.07415	0	0	N/A		
4910100	462	49	970	1432			5850	748431	0.85	0.6				24	18	1984		1	54	10	12	1996	65	2	2	77.8902	0.05205	0	0	N/A		
4910100	462	49	970	1432			5850	748431	0.85	0.6				24	18	1984		1	54	10	12	1996	65	2	2	77.8902	0.05205	0	0	N/A		
4910101	303	49	1432	1735			8400	595384	0.85	0.6				48	14	1994		1	54	10	12	1996	65	2	2	149.222	0.08692	0	0	N/A		
4910101	303	49	1432	1735			8400	595384	0.85	0.6				48	14	1994		1	54	10	12	1996	65	2	2	149.222	0.08692	0	0	N/A		
4910101	606	49	1735	2341			13046	2207437	1.034	0.6				51	11	1991		1	54	10	12	14	1996	65	2	2	91.8744	0.07954	0	0	N/A	
4910101	606	49	1735	2341			13046	2207437	1.034	0.6				51	11	1991		1	54	10	12	14	1996	65	2	2	91.8744	0.07954	0	0	N/A	
4910102	235	49	2341	2576			9653	4335064	1.034	0.6				26	11	1996		1	54	10	12	14	1996	65	2	2	117.543	0.09534	0	0	N/A	
4910102	235	49	2341	2576			9653	4335064	1.034	0.6				26	11	1996		1	54	10	12	14	1996	65	2	2	117.543	0.09534	0	0	N/A	
4910102	388	49	2576	2874			9653	4335064	1.034	0.6				26	11	1996		1	54	10	12	14	1996	65	2	2	117.543	0.09534	0	0	N/A	
4910102	388	49	2576	2874			9653	4335064	1.034	0.6				26	11	1996		1	54	10	12	14	1996	65	2	2	117.543	0.09534	0	0	N/A	
6202100	314	62	0	314			21734	9915853	1.034	0.6				24	10	1980		9	4	2	12	14	1996	64	2	2	428.412	0.19865	0	0	N/A	
6202100	314	62	0	314			21734	9915853	1.034	0.6				24	10	1980		9	4	2	12	14	1996	64	2	2	428.412	0.19865	0	0	N/A	
6202100	351	62	314	665			13984	3293693	0.877	0.6				24	9	1985		9	4	2	12	6	1996	63	2	2	111.449	0.27863	0	0	N/A	
6202100	351	62	314	665			13984	3293693	0.877	0.6				24	9	1985		9	4	2	12	6	1996	63	2	2	111.449	0.27863	0	0	N/A	
6202100	330	62	665	995			10000	2355414	0.877	0.6				36	9	1985		9	4	2	18	6	1996	64	2	2	125.218	0.27577	0	0	N/A	
6202100	330	62	665	995			10000	2355414	0.877	0.6				36	9	1985		9	4	2	18	6	1996	64	2	2	125.218	0.27577	0	0	N/A	
6202101	863	62	995	1888			8533	1001951	0.877	0.6				27	9	1991		9	4	2	13	6	1996	65	2	2	116.252	0.26058	0	0	N/A	
6202101	863	62	995	1888			8533	1001951	0.877	0.6				27	9	1991		9	4	2	13	6	1996	65	2	2	116.252	0.26058	0	0	N/A	
6208100	560	62	0	560			3600	517327	0.85	0.6				36	16	1980		9	4	5	12	2	1996	65	2	2	96.372	0.23983	0	0	N/A	
6208100	560	62	0	560			3600	517327	0.85	0.6				36	16	1980		9	4	5	12	2	1996	65	2	2	96.372	0.23983	0	0	N/A	
6207100	974	62	60	974			4318	234756	0.85	0.6				24	16	1986		9	4	5	7	12	1996	65	2	2	105.407	0.2849	0	0	N/A	
6207100	974	62	60	974			4318	234756	0.85	0.6				24	16	1986		9	4	5	7	12	1996	65	2	2	105.407	0.2849	0	0	N/A	
6208100	169	62	0	169			3000	163085	0.85	0.6				24	16	1986		9	4	5	12	2	1996	65	2	2	116.480	0.25879	0	0	N/A	
6208100	169	62	0	169			3000	163085	0.85	0.6				24	16	1986		9	4	5	12	2	1996	65	2	2	116.480	0.25879	0	0	N/A	
6208100	153	62	169	322			3771	2861877	0.85	0.6				24	16	1978		9	4	5	8	12	1996	65	2	2	124.191	0.25629	0	0	N/A	
6208100	153	62	169	322			3771	2861877	0.85	0.6				24	16	1978		9	4	5	8	12	1996	65	2	2	124.191	0.25629	0	0	N/A	
6208100	375	62	322	697			4200	347295	0.85	0.6				24	16	1985		9	4	5	8	12	1996	65	2	2	130.107	0.23896	0	0	N/A	
6208100	375	62	322	697			4200	347295	0.85	0.6				24	16	1985		9	4	5	8	12	1996	65	2	2	130.107	0.23896	0	0	N/A	
6208100	448	62	697	845			4200	347295	0.85	0.6				24	16	1985		9	4	5	8	12	1996	65	2	2	130.107	0.23896	0	0	N/A	
6208100	448	62	697	845			4200	347295	0.85	0.6				24	16	1985		9	4	5	8	12	1996	65	2	2	130.107	0.23896	0	0	N/A	
6208101	234	62	1095	1329			4483	501283	0.85	0.6				40	16	1984		9	4	5	8	10	1996	65	2	2	148	0.28411	0	0	N/A	
6208101	234	62	1095	1329			4483	501283	0.85	0.6				40	16	1984		9	4	5	8	10	1996	65	2	2	148	0.28411	0	0	N/A	
6209100	440	62	0	440			5938	663874	0.85	0.6				24	16	1994		9	4	5	12	2	1996	65	2	2	163.752	0.31031	0	0	N/A	
6209100	440	62	0	440			5938	663874	0.85	0.6				24	16	1994		9	4	5	12	2	1996	65	2	2	163.752	0.31031	0	0	N/A	
6209100	200	62	440	640			5600	1143281	0.85	0.6				34	16	1991		9	4	5	9	12	1996	65	2	2	73.1808	0.22233	0	0	N/A	
6209100	200	62	440	640			5600	1143281	0.85	0.6				34	16	1991		9	4	5	9	12	1996	65	2	2	73.1808	0.22233	0	0	N/A	
6209100	287	62	640	927			9885	2014035	0.85	0.6				24	16	1991		9	4	5	9	12	1996	65	2	2	92.6511	0.23092	0	0	N/A	
6209100	287	62	640	927			9885	2014035	0.85	0.6				24	16	1991		9	4	5	9	12	1996	65	2	2	92.6511	0.23092	0	0	N/A	
6209100	55	62	927	182			8167	1092455	0.85	0.6				36	16	1990		9	4	5	10	12	1996	63	2	2	174.883	0.23984	0	0	N/A	
6209100	55	62	927	182			8167	1092455	0.85	0.6				36	16	1990		9	4	5	10	12	1996	63</								

ESECT.	FLENGI	FNAME	FOFFER	FOFFTO	FDSCF	FDSCF	AADT	CUM.E	AXLEO	LRSPIL	COM.T	COM.Y	COM.B	TRAV	PCT.C	YR.LST	ISINFILT	DSTNO.	COUNTY	SECTN	LAWID	FINCLA	VRADT	SURTY	FASYS	SURF.C	IRI	RUT	SRI	BRI	REH.TY
6519100	351	65	825	1176		7700	385574	0.85	0.6	0.6				24	13	1980		2	1	18	12	2	1997	66	2	3	68.2748	0.1902	0	0	N/A
6520100	59	65	59	133		3000	36320	0.85	0.6	0.6				24	13	1980		2	9	20	12	2	1997	66	2	2	82.5748	0.2337	0	0	N/A
6520100	92	65	133	225		3900	262022	0.85	0.6	0.6				24	13	1985		2	9	20	12	2	1997	66	2	2	82.5748	0.2337	0	0	N/A
6520100	711	65	225	936		4629	311029	0.85	0.6	0.6				48	13	1995		2	9	20	12	2	1997	66	2	3	73.5187	0.1388	0	0	N/A
6520100	772	65	936	1707		5237	525981	0.85	0.6	0.6				24	13	1968		2	9	20	12	2	1997	66	2	3	120.936	0.23467	0	0	N/A
6521100	237	65	0	237		11000	5509392	0.85	0.6	0.6				24	13	1980		2	9	21	12	2	1997	66	2	3	142.982	0.27238	0	0	N/A
6521100	283	65	237	493		400	169233	0.85	0.6	0.6				24	13	1980		2	9	21	12	2	1997	66	2	3	142.982	0.27238	0	0	N/A
6521100	473	65	493	796		441	729663	0.85	0.6	0.6				24	13	1981		2	9	21	12	2	1997	66	2	3	142.982	0.27238	0	0	N/A
6521101	211	65	1473	1694		5418	758930	0.85	0.6	0.6				22	13	1992		2	9	21	11	2	1997	65	2	3	89.6017	0.17822	0	0	N/A
6522100	67	65	0	67		3000	3159338	0.85	0.6	0.6				22	13	1997		2	9	22	11	2	1997	65	2	3	97.1837	0.25486	0	0	N/A
6522100	706	65	67	773		2001	552525	0.85	0.6	0.6				22	13	1987		2	9	22	11	2	1997	65	2	3	127.281	0.25485	0	0	N/A
06512A0	125	65	0	125		22000	4672412	0.85	0.6	0.6				24	13	1987		6	62	12A	12	2	1996	64	2	2	81.3570	0.21112	0	0	N/A
06512A0	394	65	125	329		18000	1032502	0.85	0.6	0.6				48	10	1987		6	60	12B	12	2	1996	64	2	2	80.0047	0.24505	0	0	N/A
0651450	460	65	0	460		18500	3292070	0.85	0.6	0.6				48	10	1987		6	60	12B	12	2	1996	65	2	2	109.019	0.27643	0	0	N/A
6701100	36	67	10	460		6149	1381647	1.066	0.6	0.6				48	24	1900		3	45	14S	12	14	1996	71	2	1	0	0	0	0	N/A
6701100	70	67	0	70		14000	2991126	1.034	0.6	0.6				48	12	1990		3	46	1	12	12	1996	65	2	2	219.162	0.14681	0	0	N/A
6701100	748	67	0	818		74000	9521143	0.725	0.6	0.6				48	8	1988		6	60	10	12	12	1996	66	2	2	128.744	0.27815	0	0	N/A
6712100	1441	67	250	1691		18182	3957468	1.383	0.6	0.6				48	8	1900		6	60	10	12	12	1996	66	2	2	128.744	0.27815	0	0	N/A
6712100	916	67	890	1990		41859	3120185	1.066	0.6	0.6				48	8	1900		6	60	10	12	12	1996	72	2	1	238.993	0.25697	0	0	N/A
6713100	626	67	685	1598		18333	5690427	1.383	0.6	0.6				48	8	1900		6	60	10	12	12	1996	72	2	1	238.993	0.25697	0	0	N/A
6713101	424	67	110	1534		36000	6231682	1.383	0.6	0.6				48	8	1900		6	60	10	12	12	1996	72	2	2	187.880	0.15539	0	0	N/A
6711100	1012	67	0	1012		21909	2980453	1.383	0.6	0.6				48	10	1961		6	60	10	12	12	1996	71	2	2	200.560	0.35192	0	0	N/A
6712100	250	67	0	250		20000	4533193	1.383	0.6	0.6				48	16	1900		5	43	11	12	2	1996	73	2	1	158.289	0.25855	0	0	N/A
6714100	1441	67	182	485		7800	1697745	1.383	0.6	0.6				48	16	1900		5	73	12	12	2	1996	73	2	1	160.517	0.18034	0	0	N/A
6714100	303	67	182	485		1057	1581178	1.383	0.6	0.6				48	16	1900		5	73	12	12	2	1996	72	2	1	208.306	0.45215	0	0	N/A
6714100	591	67	1248	1246		5900	3895659	0.85	0.6	0.6				48	16	1900		5	73	12	12	2	1996	72	2	1	208.306	0.45215	0	0	N/A
6714100	663	67	685	1598		5384	3318888	0.85	0.6	0.6				48	16	1900		5	73	13	12	2	1996	72	2	2	144.919	0.26663	0	0	N/A
6715100	320	67	0	320		6297	3295851	1.62	0.6	0.6				48	4	1900		5	34	14	12	2	1996	71	2	2	118.325	0.28262	0	0	N/A
6715100	65	67	384	459		7833	2304432	0.877	0.6	0.6				48	16	1900		5	34	15	12	2	1996	72	2	1	104.771	0.24896	0	0	N/A
6715100	736	67	459	1195		7029	1435007	0.85	0.6	0.6				40	16	1991		5	34	15	12	2	1996	66	2	3	65.1671	0.27347	0	0	N/A
6715101	203	67	1498	1246		5900	3895659	0.85	0.6	0.6				48	16	1900		5	34	14	12	2	1996	72	2	1	97.982	0.25101	0	0	N/A
6715101	225	67	1148	1674		5384	3318888	0.85	0.6	0.6				24	16	1980		5	34	15	12	2	1996	63	2	3	75.795	0.2628	0	0	N/A
6715101	697	67	1674	2371		4220	861544	0.85	0.6	0.6				24	16	1980		5	34	15	12	2	1996	63	2	3	96.9287	0.26129	0	0	N/A
6716100	1140	67	0	1140		5000	531642	0.877	0.6	0.6				24	20	1995		5	34	15	12	2	1995	65	2	3	73.6782	0.26191	0	0	N/A
6716100	106	67	1140	1246		5900	3895659	0.85	0.6	0.6				24	20	1995		5	34	15	12	2	1995	66	2	3	131.841	0.23884	0	0	N/A
6717100	412	67	1246	1418		13000	6804579	0.877	0.6	0.6				26	20	1985		10	38	16	13	6	1997	66	2	3	151.700	0.25862	0	0	N/A
6717100	445	67	141	586		8128	7254623	0.85	0.6	0.6				24	20	1985		10	38	17	13	6	1997	66	2	3	166.488	0.2334	0	0	N/A
6718100	610	67	0	610		7700	1176508	0.85	0.6	0.6				24	15	1973		10	38	17	12	2	1987	66	2	3	126.260	0.21056	0	0	N/A
6718100	127	67	610	737		9100	2302692	1.034	0.6	0.6				24	15	1962		10	61	18	12	2	1987	63	2	3	118.138	0.28943	0	0	N/A
6718100	38	67	737	765		4300	3895197	1.62	0.6	0.6				36	8	1986		10	61	18	12	14	1997	65	2	3	228.901	0.33488	0	0	N/A
6719100	111	67	38	149		4300	3895197	1.62	0.6	0.6				24	9	1975		10	61	18	17	14	1997	71	2	1	378.485	0.25114	0	0	N/A
6719100	629	67	38	149		5500	1436076	1.62	0.6	0.6				24	9	1950		10	61	19	12	14	1997	71	2	2	265.181	0.26629	0	0	N/A
6719100	78	67	778	856		3700	820881	0.85	0.6	0.6				24	15	1990		10	61	19	12	2	1997	66	2	3	134.476	0.27675	0	0	N/A
6719100	696	67	856	1552		3600	9758453	1.383	0.6	0.6				24	15	1990		10	61	19	12	2	1997	65	2	3	151.741	0.27294	0	0	N/A
6720100	451	67	41	690		4300	3895197	1.62	0.6	0.6				24	15	1980		10	61	19	12	2	1997	72	2	2	181.725	0.23228	0	0	N/A
6720100	112	67	990	1102		5810	1850912	0.85	0.6	0.6				34	15	1987		10	11	20	12	2	1997	62	2	3	193.768	0.34458	0	0	N/A
6720101	83	67	1102	1185		6600	2102585	0.85	0.6	0.6				34	15	1987		10	11	20	12	2	1997	65	2	3	169.070	0.33099	0	0	N/A
6720101	622	70	522	1807		5850	946170	0.85	0.6	0.6				24	15	1992		10	11	20	12	2	1997	66	2	3	214.152	0.32421	0	0	N/A
7001100	59	70	522	1379		3045	330510	0.85	0.6	0.6				22	21	1995		3	66	1	11	2	1996	66	2	2	155.041	0.33762	0	0	N/A
7001100	163	70	852	813		6210	4004480	0.85	0.6	0.6				24	21	1983		3	66	1	12	2	1996	63	2	2	117.830	0.24673	0	0	N/A
7001100	51	70	813	864		11000	7093282	0																							

FSECT	FLENGT	FNAME	FOFFER	FOFFTO	FOFFSC	FDESC	AADT	CUM F	AXLEQ	LRSP	COM T	COM Y	COM B	TRAV	ECT C	YR	LST	ISINFLT	DSTNO	CONTY	SECTN	LAWID	ENCLA	VRADT	SURTY	FASYS	SURF C	IRI	RUT	SRI	BRI	REH TY
82014100	202	79	373	171	373	168181	0.85	0.6	0.6	0.6				22	18	1996			1	48	14	11	2	1996	65	2	139.977	0.10683	0	0	N/A	
82014100	303	78	373	178	373	2750	0.85	0.6	0.6	0.6				22	18	1996			1	48	14	11	2	1996	65	2	113.462	0.10488	0	0	N/A	
82014100	303	78	373	178	373	1900	0.85	0.6	0.6	0.6				22	18	1996			1	48	14	11	2	1996	65	2	115.204	0.26198	0	0	N/A	
82011001	446	82	583	137	583	10120	0.85	0.6	0.6	0.6				22	21	1977			3	46	1	11	2	1996	65	2	132.957	0.19695	0	0	N/A	
82011001	721	82	583	1304	1304	4107	0.85	0.6	0.6	0.6				22	21	1977			3	46	1	11	2	1996	65	2	70.454	0.21568	0	0	N/A	
82011011	734	82	1304	2038	2038	3500	0.85	0.6	0.6	0.6				22	21	1985			3	46	1	11	2	1996	65	2	86.2302	0.2025	0	0	N/A	
82011021	102	82	2038	2038	2038	3850	0.85	0.6	0.6	0.6				22	21	1980			3	37	2	11	2	1997	63	2	109.666	0.19695	0	0	N/A	
82021001	166	82	0	145	145	4200	0.85	0.6	0.6	0.6				22	21	1980			3	37	2	11	2	1997	63	2	109.666	0.19695	0	0	N/A	
82021001	174	82	0	145	145	4350	0.85	0.6	0.6	0.6				22	21	1980			3	37	2	11	2	1997	63	2	109.666	0.19695	0	0	N/A	
82021001	471	82	622	145	622	4350	0.85	0.6	0.6	0.6				22	21	1979			3	37	2	11	2	1997	64	2	109.666	0.19695	0	0	N/A	
82021001	336	82	622	758	758	5375	0.85	0.6	0.6	0.6				50	21	1991			3	37	2	12	2	1997	65	2	109.666	0.19695	0	0	N/A	
82021011	412	82	758	1170	1170	7100	0.85	0.6	0.6	0.6				30	21	1991			3	37	2	12	2	1997	65	2	109.666	0.19695	0	0	N/A	
82021011	51	82	1170	1221	1221	6900	0.85	0.6	0.6	0.6				32	21	1984			3	37	2	12	2	1997	65	2	109.666	0.19695	0	0	N/A	
82021011	59	82	1221	1280	1280	6700	0.85	0.6	0.6	0.6				25	21	1984			3	37	2	12	2	1997	64	2	109.666	0.19695	0	0	N/A	
82021011	390	82	1380	1720	1720	16600	0.85	0.6	0.6	0.6				22	21	1984			3	37	2	12	2	1997	65	2	109.666	0.19695	0	0	N/A	
82031001	106	82	0	106	106	5900	0.85	0.6	0.6	0.6				22	21	1971			3	37	2	11	2	1997	65	2	120.250	0.34588	0	0	N/A	
82031001	278	82	106	384	384	5250	0.85	0.6	0.6	0.6				24	16	1984			3	14	3	12	2	1996	65	2	106.665	0.08102	0	0	N/A	
82031001	925	82	384	1309	1309	5535	0.85	0.6	0.6	0.6				24	16	1983			3	14	3	12	2	1996	65	2	93.2937	0.08562	0	0	N/A	
82041001	220	82	0	220	220	4988	0.85	0.6	0.6	0.6				24	8	1983			7	14	3	12	14	1996	65	2	92.7590	0.15179	0	0	N/A	
82041001	390	82	560	881	881	4100	0.85	0.6	0.6	0.6				35	16	1985			7	14	4	11	2	1996	65	2	123.080	0.1827	0	0	N/A	
82041001	187	82	881	1078	1078	4100	0.85	0.6	0.6	0.6				35	16	1985			7	14	4	11	2	1996	65	2	123.080	0.1827	0	0	N/A	
82041011	152	82	1078	1230	1230	3950	0.85	0.6	0.6	0.6				22	16	1985			7	14	4	11	2	1996	65	2	133.432	0.1288	0	0	N/A	
82041011	196	82	1230	1426	1426	3800	0.85	0.6	0.6	0.6				36	16	1980			7	14	4	11	2	1996	65	2	117.248	0.12322	0	0	N/A	
82041011	160	82	1426	1596	1596	3800	0.85	0.6	0.6	0.6				36	16	1980			7	14	4	11	2	1996	65	2	117.248	0.12322	0	0	N/A	
82051001	202	82	202	496	496	4000	0.85	0.6	0.6	0.6				22	16	1985			7	70	5	12	2	1996	65	2	95.7924	0.07699	0	0	N/A	
82051001	170	82	496	689	689	4000	0.85	0.6	0.6	0.6				36	16	1985			7	70	5	12	2	1996	66	2	95.7924	0.07699	0	0	N/A	
82051001	327	82	689	996	996	4600	0.85	0.6	0.6	0.6				36	16	1980			7	70	5	12	2	1996	66	2	132.336	0.13448	0	0	N/A	
82051011	83	82	996	1079	1079	4600	0.85	0.6	0.6	0.6				24	16	1980			7	70	5	12	2	1996	65	2	153.654	0.17401	0	0	N/A	
82051011	136	82	1079	1215	1215	4600	0.85	0.6	0.6	0.6				24	16	1980			7	70	5	12	2	1996	65	2	153.654	0.17401	0	0	N/A	
82051011	470	82	1215	1672	1672	4600	0.85	0.6	0.6	0.6				24	16	1980			7	70	5	12	2	1996	65	2	153.654	0.17401	0	0	N/A	
82051011	170	82	1672	1879	1879	4600	0.85	0.6	0.6	0.6				24	16	1980			7	70	5	12	2	1996	65	2	153.654	0.17401	0	0	N/A	
82051011	302	82	1877	2179	2179	7900	0.85	0.6	0.6	0.6				48	19	1992			7	70	5	12	12	1996	65	2	92.2764	0.05589	0	0	N/A	
82061001	107	82	0	107	107	7100	0.85	0.6	0.6	0.6				48	19	1992			7	70	5	12	12	1996	65	2	92.2764	0.05589	0	0	N/A	
82061001	96	82	107	205	205	4500	0.85	0.6	0.6	0.6				24	16	1984			7	70	5	12	12	1996	65	2	84.5076	0.05813	0	0	N/A	
82061001	452	82	205	657	657	4500	0.85	0.6	0.6	0.6				24	16	1984			7	70	5	12	12	1996	65	2	84.5076	0.05813	0	0	N/A	
82061001	665	82	657	1176	1176	4500	0.85	0.6	0.6	0.6				24	16	1984			7	70	5	12	12	1996	65	2	84.5076	0.05813	0	0	N/A	
82071001	665	82	1176	1452	1452	7000	0.85	0.6	0.6	0.6				24	16	1984			7	70	5	12	12	1996	65	2	84.5076	0.05813	0	0	N/A	
82071001	77	82	0	77	77	2600	0.85	0.6	0.6	0.6				24	16	1986			7	70	6	11	2	1996	63	2	139.503	0.13952	0	0	N/A	
82071001	72	82	77	149	149	2600	0.85	0.6	0.6	0.6				24	16	1986			7	70	6	11	2	1996	65	2	123.336	0.13448	0	0	N/A	
82071001	164	82	149	313	313	2600	0.85	0.6	0.6	0.6				24	16	1980			7	70	6	11	2	1996	65	2	153.654	0.17401	0	0	N/A	
82071001	373	82	313	686	686	2600	0.85	0.6	0.6	0.6				24	16	1980			7	70	6	11	2	1996	65	2	153.654	0.17401	0	0	N/A	
82071001	389	82	686	1048	1048	2600	0.85	0.6	0.6	0.6				24	16	1980			7	70	6	11	2	1996	65	2	153.654	0.17401	0	0	N/A	
82071011	59	82	1048	1452	1452	4500	0.85	0.6	0.6	0.6				24	16	1984			7	70	7	12	2	1995	65	2	69.9891	0.04598	0	0	N/A	
82071011	59	82	1452	1511	1511	4500	0.85	0.6	0.6	0.6				24	16	1984			7	70	7	12	2	1995	65	2	69.9891	0.04598	0	0	N/A	
82081001	59	82	0	59	59	4500	0.85	0.6	0.6	0.6				24	16	1980			7	70	7	12	2	1995	65	2	197.469	0.14242	0	0	N/A	
82081001	243	82	59	302	302	4500	0.85	0.6	0.6	0.6				24	16	1980			7	70	7	12	2	1995	65	2	158.448	0.08075	0	0	N/A	
82081001	334	82	302	636	636	2700	0.85	0.6	0.6	0.6				24	16	1980			7	70	7	12	2	1996	65	2	158.448	0.08075	0	0	N/A	
82081001	56	82	636	748	748	6600	0.85	0.6	0.6	0.6				24	16	1980			7	70	7	12	2	1996	65	2	158.448	0.08075	0	0	N/A	
82081001	142	82	748	946	946	10000	0.85	0.6	0.6	0.6				24	16	1980			7	70	7	12	2	1996	65	2	158.448	0.08075	0	0	N/A	
82081001	780	82	946	1726	1726	14143	0.85	0.6	0.6	0.6				44	16	1990			7	70	7	12	14	1996	65	2	172.493	0.07129	0	0	N/A	
82081011	264	82	1726	1990	1990	2538	0.85	0.6	0.6	0.6				24	1																	





