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Using GIS to Identify Pavement Preservation Projects

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ABSTRACT

Pavement management systems (PMS) are employed by many departments of transportation (DOTs) and other managing agencies to store information regarding the roadway network. Many of these PMSs can perform needs analysis on a section by section basis within the network. When it comes to moving from the network level to the project level, agencies need to combine multiple sections for a pavement preservation project. This study evaluates the use of GIS and information provided from the TxDOT Pavement Management Information System (PMIS) to identify locations for possible pavement preservation projects. The goal is to build a method that finds possible projects that are longer than the section length within PMIS. This study focuses on the TxDOT network within Brazos County and discusses some of the stumbling blocks associated with creating the method and the final implementation of the method. The method is based on creating rasters from the needs estimate information from PMIS. Using points assigned to each roadway, the roads are evaluated to and from each point to determine how long it takes to travel from point to point. The areas with the slowest speed, creating the longest travel time are assumed to be in the worst condition and are highest consideration for pavement preservation projects. The technique is applied to the TxDOT network in Brazos County and a map is created illustrating the high priority areas.
INTRODUCTION

The Texas Department of Transportation (TxDOT) manages approximately 195,000 lane-miles of pavement, including the busiest interstates and the smallest farm-to-market (FM) roads in the most rural portions of the State. The pavements that make up this vast system represent the most valuable asset within the publically owned Texas transportation system. Due to the valuable nature of pavements, maintaining, repairing, and improving the system is one of TxDOT’s highest priorities.

To help manage the pavement system, TxDOT created the Pavement Management Information System (PMIS). PMIS is similar to other pavement management systems (PMS) used by other DOTs and managing agencies. One of, if not the primary ability of PMIS is to function as the information database for the pavements in Texas. Pavements are divided into sections, typically 0.5-mile in length. Each of these sections is rated annually for distress and ride quality. Distress and ride quality are combined to create a condition score for each section of pavement. PMIS holds this information in an MSAccess database. PMIS has been further developed to perform network-level analysis to help pavement managers determine the needs of the system and possible funding requirements. One of the primary network-level tools in PMIS is the Needs Estimate which takes the information collected from annual surveys and determines if a section of pavement requires a maintenance and rehabilitation (M&R) action and what level of action should be taken. How a section is identified in the Needs Estimate contributes significantly to the application of the technique developed through this project.

While the Needs Estimate provides helpful information regarding sections of pavement, there remains a disconnection between making section related decisions and project related decisions. PMIS is not currently capable of identifying possible M&R projects; rather it remains fixed in the realm of pavement sections. In reality, TxDOT seldom creates a pavement preservation project that is only 0.5-mile in length. Due to economies of scale, it is more advantageous and economical to have projects that span multiple sections. When creating projects that span multiple sections, it is probable that all the sections within the project will not have the same M&R suggestions created by the Needs Estimate. In fact, it would not be uncommon for three sections to have medium rehabilitation suggested, while two sections could have preventative maintenance, one section have light rehabilitation, and two more with needs nothing suggested. This project would include eight sections for an approximate length of four miles. The question now becomes, is this project a good selection when compared to other possible projects in the network?

This project seeks to answer that question by using GIS to identify possible pavement preservation projects. The identification of these projects is based on M&R suggestions from TxDOT’s PMIS. Due to the vast number of sections within the TxDOT network, the project focuses on TxDOT managed roads in Brazos County. The ultimate goal is to create a technique in GIS that will help pavement managers look beyond information about a single pavement section and identify pavement preservation projects that span multiple sections.
LITERATURE REVIEW

It is not uncommon for roadway managing agencies to use GIS to display the network and display certain characteristics of the network. The visualization of these characteristics is usually used to help make decisions about what should be done to the system and where it should be done. There have been cases where GIS was used to create two different maps that could be combined to create a map that would help managers make decisions. One of the maps displays pavement condition, helping managers identify poor sections of road, while the other displays traffic volume, helping managers identify high priority areas (Obaidat and Al-kheder 2006).

Other times, GIS is used to identify how the roadway network interacts with its surroundings and how the condition of the surroundings should affect roadway decisions. This is particularly useful in mountainous regions where landslides can be detrimental to transportation. In areas such as this, it serves transportation managers well to be able to visualize pavement areas and the proximity to areas susceptible to landslide. This information can be mapped and show decision makers where money should be spent to ensure the network remains in good working order (Panth, et al. 2010).

North Carolina Department of Transportation (NCDOT) has employed the use of GIS with its PMS to create M&R decision maps. This is similar to the PMIS Needs Estimate in that the M&R suggestions are built on annual survey information within the PMS. This survey information is displayed through GIS and sections requiring work are easily seen (Zhou, et al. 2010). Alvarez, et al. (2007) discusses a similar display for the roadway network in Badajoz, Spain. In this paper, the broad condition of the roadway section is displayed in GIS to help managers identify poor sections of road. This type of display could be done using condition score information from PMIS, but again the problems arise as to how and move beyond sections and display actual M&R projects.

Arizona recently overhauled its PMS in an effort to build a system that more effectively communicated between network-level and project-level (Li, et al. 2006). Smith and Fallaha (1992) recognized the need to identify sections requiring work, but also stated that many DOTs apply the same treatment across multiple sections, implying that the need existed for pavement management systems to look beyond sections when evaluating possible projects. These authors were adamant that for pavement management systems to be effectively applied at the project-level, that is, the level where detailed plans and contract documents are created, multiple sections must be included. The time between the two aforementioned papers (1992 to 2006) illustrates that the ability to evaluate beyond a pavement section remains limited.
METHODOLOGY

As previously stated, many DOTs and other pavement managing agencies use extensive pavement management systems that are in part a large database containing information regarding the network. Often these pavement management systems are able to perform network analysis to develop a broad sense of the system and offer possible scenarios related to this broad assessment. The goal of this methodology is to look deeper than the network and isolate areas that require work. These areas are longer/larger than the sections the database is built upon.

The first step in the process is the ability to map information regarding the sections within the database. TxDOT’s PMIS has the capability to perform this function. The methodology of this project focuses on steps beyond this point, if an agency does not yet have these capabilities, the ability to map this kind of information must first be achieved.

As a managing agency, it must first be decided what type of information should be aggregated to help make decisions. For pavement preservation projects it could be a condition index that aggregates distresses and creates an overall rating, individual distresses, ride quality, or some form of needs assessment. Once the parameter has been established, how these parameters affect the system must be determined. The roadways on the system will be evaluated from a cost perspective, thus managers must decide how an increase or decrease in the parameter can affect the users. This is most easily understood in speed, for example when a parameter gets worse, the speed at which travel can occur is lessened, thus increasing the cost to the user. By weighting decision parameters in terms of time, it more easily facilitates the use of cost distance and cost allocation within GIS.

To utilize cost distance and cost allocation, the information regarding the sections within the network must be rasterized. An agency should be careful to limit the number of descriptions used in the measuring parameter. For example, use classifications not unique values, such as very poor, poor, fair, good, and very good. This limitation will help during the rasterization process because each measurement of the parameter must be selected in GIS using select by attributes. Once the section descriptions are rasterized, weights must be assigned to each description through the use of the raster calculator. From a cost perspective, the agency will typically be concerned with how much time (i.e. seconds) it takes to travel a unit of length (i.e. feet). Using the rasters created by weighting the descriptors, a mosaic can be created that can be used to run both cost distance and cost allocation.

Before the cost allocation can be generated, the managing agency must decide upon what to allocate the cost. A discussion should proceed as to how long the agency feels pavement preservation projects should be. This discussion should include items such as economies of scale, construction project time, traffic control issues, and any other parameters the agency feels are important. Regardless of what is chosen, the GIS application will only provide help in
identifying candidate sections, decision makers will have the final say and the ability to adjust as circumstances warrant. GIS and the construction points function, within the editor, allows the user to define points along each of the roadways at the identified interval used to help identify possible preservation projects.

The points applied to the roadway can be used to run the cost allocation and cost distance. Essentially, GIS is used to spread out from each point until it draws nearer to another point at which time it changes its allocation to the point closer. Because the mosaic created follows rasters that are only along roadway, the cost allocation and cost distance essentially drive down the roads and assign themselves to the nearest point. It is important when performing this process that the GIS operator understands that the cell size must be realistic but also small enough to avoid cells within the raster combining. This becomes a problem in divided highway areas where a cell size too big can cause joining and therefore cost allocations and cost distance no longer accurately apply to only one roadway. For this reason, the method may have to be excluded from urban boulevard sections where opposing traffic is divided with a narrow median and cell size cannot be reduced to a reasonable level. The cost allocation created along the roadways can now be converted back to vector format.

Using the polygons created from the cost allocation raster, zonal statistics can be developed that provide information regarding the maximum amount of time within the polygon. The roadway features are intersected with the polygons and the output of the intersection is forced to be lines so that the roadway within the cost allocation is established. GIS is used to calculate the geometry of each line created from the intersection. The zonal statistics table can be joined with the attribute table of this newly created line shapefile. During this joining process, the users must take care to make sure the tables are joined based on the proper defining element within each table. With the joined tables and the recalculated length, the managing agency can compute the length per unit time it takes to travel on each cost allocation section. Possible project areas will be those with the lowest length per unit time (i.e. ft/s), thus implying it cost the users more by having to travel slower.

APPLICATION AND DISCUSSION

The specific application of this project focuses on Brazos County, a county within the 10 county Bryan District within TxDOT. The isolation of Brazos County is done because the network can get extremely large and the amount of information can cause computational problems. The Bryan district contains 6752 pavement sections for just over 7000 lane miles. The data is also constrained by the information obtained during yearly surveys. TxDOT’s goal is to survey 100% of pavement annually, however sections are often skipped because of construction activities and thus portions of the network receive no information. PMIS does not currently use a place holder when projects are under construction, therefore roadways within the
network can become disconnected, an issue when performing this type of analysis. A suggestion to the managing agency would be to provide some sort of placeholder data for sections that do not get rated, thus allowing the network to stay intact from an analysis standpoint from year to year.

A shapefile was obtained from TxDOT containing FY 2008 needs estimate information for Brazos county. A TxDOT Brazos County roadway centerline file was obtained from TNRIS to compare the roadways surveyed for the needs estimate with the entire network in Brazos County. This information was mapped using GIS and is displayed in the following figures.

![Figure 1 - Brazos Co. Roadway Centerlines](image1)

![Figure 2 – Brazos Co. Needs Estimate](image2)

From Figure 1 and Figure 2, it is clear that the needs estimate occurs on actual pavement, not along the centerline, thus the centerline can only be used for reference. For example, in a divided highway section, the centerline will most likely run down the median between the two roadbeds, but survey information will occur on each roadbed. This is illustrated in Figure 3.
Before working with the data, the data frame was changed to an appropriate working projection, NAD 1983 Stateplane Texas Central. This projection uses the working linear unit of the English foot. The needs estimate information was projected into this projection system mainly because the information provided from TxDOT was in geographic coordinates. From Figure 2, it is known that needs estimate information suggest possible M&R actions for a section of pavement. There are five possible M&R suggestions, needs nothing (NN), preventative maintenance (PM), light rehabilitation (LRhb), medium rehabilitation (MRhb), and heavy rehabilitation (HRhb). Using select by attributes, each section was rasterized based on its M&R suggestion. Once the sections of pavement were turned into rasters, a cost must be associated with each M&R suggestion. This cost could vary depending on what a managing agency chose to use, but for this study the obvious assumption was made that HRhb would cause traffic to go the slowest and NN would allow traffic to move uninhibited. With this in mind, the following costs were assigned to each rasterized M&R suggestion:

- NN = 70 mph = 9.7 ms/ft
- PM = 65 mph = 10.5 ms/ft
- LRhb = 58 mph = 11.8 ms/ft
- MRhb = 50 mph = 13.6 ms/ft
- HRhb = 40 mph = 17.0 ms/ft
These costs were assigned using the raster calculator and dividing each rasterized M&R suggestion by itself to get a value of one and then multiplying by the cost shown above. A mosaic was created of these rasters that could be used to essentially “drive” down each roadway. When creating this mosaic, the maximum operator was chosen, implying that the worst case scenario would always be chosen if two rasters intersected. This is a conservative approach which makes sense when determining where pavement preservation is needed. This mosaic operation is illustrated in the Figure 4.

![Figure 4 – Mosaic Operation in GIS using Maximum Operator](image)

With the mosaic, a cost allocation and cost distance could be created if points were defined on which to allocate the costs. Because reference markers are assigned to roadways, it makes sense to use reference markers for the points of allocation. For the project, a text file was obtained that consisted of latitude and longitude information for the reference markers (RM) in the Bryan District. This information was imported into MSAccess and saved as a .mdb, a personal database file recognized by GIS. Using the Add XY Data tool under the File menu in GIS, this information was turned into a shape file, allowing for the visualization of RMs in the Bryan District. The screen shot below illustrates this operation.
Through the use of the GIS intersection function, the RMs in Brazos County were isolated. RMs are not placed on the roadway, rather they are mounted to a sign on the roadside, thus the location provided in the text file did not exactly correspond to a point on the roadway and because the rasters were created to move along the roadway, the RMs had to be intersected with roadways using a tolerance value. A 20-foot tolerance was used as illustrated below.

The cost allocation and cost distance function can now be used with the intersected reference markers as the input and the mosaic raster as the cost raster. The cost allocation function creates rasters allocated to each reference marker along the line. This is displayed in the following figure, a zoomed-in look at FM 2154 and FM 159.
This cost allocation was then converted to polygons, creating vector data associated with each point used as an input parameter. Some of these polygons created contained more than one roadway, thus the roadways within the polygons were dissolved into a linear feature and the length was carried through the dissolve process and summed for further calculation. This is illustrated in Figure 8.

Figure 8 – Dissolve Function Summing the Length in Each Polygon
Zonal statistics were run on the created polygons using the cost distance raster previously created. Zonal statistics provides information regarding the maximum amount of time in each polygon. The zonal statistics table can be joined with the dissolved layer and a length per unit time can be calculated for each dissolved entry. The assumption is that those entries with the slowest unit per time will be possible pavement preservation projects. Did it work? The answer is kind of, Figure 9 displays what occurred.

Figure 9 – Method Output Using RMs

Figure 9 displays the grouping of nine possible pavement preservation areas created by the method. It is clear that multiple roads have been grouped together, but jumping from road to road is not better than evaluating only sections. This occurs for two reasons. The first is that in the initial evaluation, the defined cell size for the rasters was ¼-mile, 1320’. This large of a cell size caused cells to combine and create large polygons around the points used as input parameters. The other cause was the fact that in divided highway areas, reference markers are assigned to the centerline of the roadway, not the roadbeds. The intersection of the RMs and the roads assigned the RM to only one of the roadbeds, but when creating a cost allocation each roadbed was included. This inadvertent overlap caused grouping issues and incorrect lengths associated with the input parameters.

To overcome these problems a method had to be developed that created points along the roadway lines. These points could be used as the input parameters for a cost allocation with a smaller cell size. To develop this method, FM 974 was chosen as a test case. The needs estimate for FM 974 was exported to its own layer and each component of the needs estimate was rasterized to a cell size of 100’. This is a small cell size and it is important for an agency to understand the limits of its data and ensure this small of a cell size is appropriate. It is also
important to remember that a cell size this small and a large network can lead to computational problems. FM 974 was unsplit to create a single line feature, the needs estimate feature was exported in its segmented form. During the unsplit process, the length of FM 974 was preserved by summing it through the unsplit command. This is displayed below.

![Figure 10 – Unsplit Command (FM 974)](image)

The goal now is to add points along the roadway that can be used as input features during the cost allocation. An agency should decide an optimum distance to evaluate preservation projects, for the study, two miles was chosen. A new point shapefile was created in ArcCatalog and added in ArcMap. An editing session was started and the Construction Point command was used to add points to the unsplit line of FM 974. Points were also added to the beginning and end of the line. This command appears in Figure 11 as it is seen in ArcMap.

![Figure 11 – Add Construction Points (FM 974)](image)
The process originally described of running a cost allocation and cost distance is performed. After the polygons have been created, the unsplit FM 974 line is intersected with the polygons to get the length of each roadway. The zonal statistics are generated for the polygons using cost distance and the statistics table is joined to the line shapefile created by the intersection of FM 974 and the polygons. The length per unit time is calculated using the field calculator and then sorted ascending. The slowest sections represent the highest need for pavement preservation. This process is represented in the following screenshots and ultimately a map illustrated in Figure 15.

Figure 12 – Zonal Statistics Function and Table Created
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Figure 13 – Calculating Length per Unit of Time

Figure 14 – Identification of High Priority Areas on FM 974
The longer of the three sections illustrated in Figure 15 is approximately 3-miles long, while the other sections are approximately 1-mile long. This method is showing promise with the ability to identify a section approximately 3-miles in length. The method is further expanded to the entire network. To continue this expansion, the unsplit command must be applied to the needs estimate information. The unsplit command struggles with a large number of inputs, therefore the undivided roadways were exported to a new layer and unsplit. Construction points need to be added to the unsplit roadways, but GIS will not allow for a mass construction point placement. Because the study area was isolated to Brazos County it was possible to select each undivided roadway and assign construction points to each individually. As the network increase in size, this action will become much more cumbersome. For further implementation, a managing agency, such as TxDOT, should make sure that information collected on a section basis has a corresponding unsplit line. This unsplit line must follow the roadbeds and not the

Figure 15 – Sample Map of FM 974 with High Priority Sections
centerline, thus construction points can be added to each roadbed for further evaluation. Initially it will take some time to add construction points, but the points can be saved as a shapefile and used from year to year. In short, the data collected by the agency must follow the roadbeds and should not change unless new capacity is constructed. It is also important that sections are not skipped, if a section is under construction, a place holder should be added in the data so that the pavement network remains uniform. This is the way the centerline files are maintained, but the section files such as the needs estimate have holes that need to be filled for further implementation.

The process was carried through for the entire network after unsplitting and adding construction points. The same calculations using the zonal statistics for the entire network were computed and sorted to find the top 20 priorities. These priorities were mapped to help visualize the locations. Also mapped was a ¼-mile buffer around the original needs estimate HRhb sections. These sections represent the “hot-spots” for preservation needs. It is likely some of the priorities will include these sections. This map is illustrated in Figure 16.
Figure 16 – Priority Map with Hot-spots

Figure 17 is a final map illustrating the entire Brazos County systems.
The map is laid over an image from Google Earth. This image has been rectified into a .tif in ArcGIS so that it can be used for other geospatial functions. It was rectified by saving the roadways from the needs estimate to a KML, opening in Google Earth, saving the image, and then adding control points using the Georeferencing toolbar in ArcGIS. Mapping the information over an aerial image helps present the information to managers who are more concerned with physical location and not the specific details. The method shows additional
promise because the map in Figure 16 isolates a location where FM 158 and FM 1687 almost intersect high priority sections. The ability to add these sections together would create a project approximately four miles long. In addition to these sections, just SE along FM 158 is another high priority area almost one mile long, thus implying that a preservation project could be created over five miles in length, a more appropriate length than the ½-mile sections survey in the needs estimate.

The use of network analysis and linear referencing was evaluated, but these functions within GIS are more concerned with extensive networks. While the entire roadway system of a county is being evaluated, for pavement preservation projects each road needs to be analyzed individually, making the use of rasterized ratings and cost allocation a more streamlined and appropriate approach.

CONCLUSION

There are certain holes in the data provided by TxDOT. These holes are associated with the annual surveys and the fact that TxDOT skips sections and does not include a data placeholder. One of the key components of complete implementation of a technique such as this is a defined data collection method that creates a homogenous roadway system from year to year. The roadways should also consist of the rating sections and an unsplit line. The construction points can be added to the unsplit lines and carried in a separate shapefile from year to year. Cell size should be set to a size reasonable with the data, but small enough to avoid merging during the mosaic to raster technique. This can create problems with divided highways with small medians and must be carefully evaluated during the priority setting. Lastly, mapping the roadways and the preservation project possibilities on an aerial image supports the presentation of what the method offers to managers.
REFERENCES


