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GIS Based Pavement Maintenance: A Systematic Approach

Robert J. Kmetz
rkmetz@purdue.edu

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Purdue University West Lafayette, Indiana

College of Technology

G.I.S. Based Pavement Maintenance: A Systematic Approach

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A Directed Project Report

By

Robert J Kmetz

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Committee Member	Approval Signature	Date
Bryan J Hubbard, Chair		
Wesley G Crawford		
Yi Jiang		

GIS Based Pavement Maintenance System:

A Systematic Solution

Purdue University

Robert Kmetz

3/14/11

Bryan J. Hubbard, Chair
Building Construction Management

Wesley G. Crawford
Building Construction Management

Yi Jiang
Building Construction Management

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Abstract

According to 2008 Federal Highway Administration (FHWA) statistics, there are 2,734,102 miles of paved public roads in the United Sates, with an additional 1,324,245 miles of unpaved public roads. Road conditions deteriorate with time as the result of weather effects, deicing salts, and vehicle loads. The most common pavement distress includes cracking, rutting, and potholes. These pavement defects must be repaired to restore the pavement to a satisfactory service level for road users. According to the FHWA, in 2006 approximately $54.2 billion dollars was spent on maintenance and expansion, just on U.S. highways alone.

Routine maintenance is a cost effective way to maintain pavement service level. Many cities are now starting to implement Maintenance Improvement Plans (MIP's). These long-range plans will help extend the life of pavement and reduce the long-term cost of road maintenance. It is the adage of "pay a little now rather than a lot later."

Along with the MIP, using a Geographic Information Systems (GIS) can help cities better manage their roads by graphically representing the MIP. This information can then be used to inform residents of upcoming road work, inform the city council on areas that are in need of repair, plan for future repairs, and track the troubled roads that seem to always be in need of repair. Many organizations are seeing the benefits of collecting roadway data and keeping a database. For cities that may not have GIS or the money to spend on an engineering firm to rate their roads, there are still ways to gather the needed data. A maintenance plan is essential, and procedures must be put in place to gather the data, analyze that data, and then implement the plan. These procedures to implement the maintenance plan and use a GIS to track the plan will be examined in this paper.

1. Introduction

To manage thousands of miles of roadways, Georgia, “(GDOT) has adopted and been actively using GIS technology to improve its18,000-centerline-mile (28,962-km) system's highway pavement management for the past few years. An Oracle client/server and GIS-based pavement management module were developed by Georgia Tech and have been successfully implemented by GDOT since 2000” (Tsai, 2004).

1.1 Maintenance Improvement Plan

The purpose of the MIP is to rate the condition of a city’s, county’s, or state’s roadways. This is done at first to determine the existing conditions and then to implement a plan that will enhance the overall life cycle of the road. Studies have shown that it is much more cost effective to maintain good roads as opposed to rehabbing roads that are in poor condition.

“From maintenance management and pavement management perspectives, it is useful, even imperative, to assess the effectiveness of individual maintenance treatments (or specific combinations thereof) in the short term as accurately as possible. Such maintenance effectiveness evaluation is critical to maintenance management because it provides a basis to compare the effectiveness of maintenance across various categories of attributes such as treatment type, material used, procedure, or even work source (for instance, work done in-house versus work let out on contract).” (Labi, 2003).

The implementation of the MIP will not only provide a city with a means to maintain their roadways but will also:

- Provide safer and more reliable roads, which in turn will make for a more efficient transportation system.
- Provide a more effective and cost beneficial means of maintaining roadways.
- Identify a plan to improve road quality as well as maintain the entire roadway system.

- Enhance the ability to extend pavement life, which in turn will result in long-term savings to the taxpayers.

The process involved in developing the MIP consists of four steps. These include: roadway condition assessment, maintenance strategies and improvement recommendations, prioritization of roadway improvements, and development of the preliminary cost estimate.

1.2 Geographic Information System

GIS is a system that integrates hardware and software to facilitate the management, analysis, and graphical representation of all forms of geospatially referenced data. GIS allows the user to interpret, question, track, and visualize data in ways that will establish trends, patterns, and relationships, in the form of maps, reports, and charts. GIS helps answer questions and solve problems by looking at data in a way that is quickly understood and easily shared the collected data can be displayed on a map to allow for better tracking and decision-making when it comes to the users' needs. In the case of road information, GIS would have extensive pavement data. Additional information may include traffic volume, sign retroreflectivity, as-built information, political districts, population, weather data, and any other data that may have an effect on the road functioning at a high level.

GIS works well for areas with thousands of miles of roadways, however, it is also useful for smaller communities with smaller volume roads. The need for data collection and management is common for all communities. Budgets have to be made and roads go through the same degradation process no matter where they are. In Wisconsin, the Department of Transportation developed a plan to aid in keeping track of lower volume roads, Wisconsin Information System for Low-Volume Roads (WISLR). "Managers of low-volume roads face numerous challenges. Budgeting, routine and capital maintenance decision-making, and applying best practices or the latest materials often stymie managers of small systems" (Ebeling, 2007).

GIS has come along way over the years. We are now seeing the use of 3-D imagery and virtual reality. Using Google Earth, buildings in cities like Chicago and New York may be viewed in 3-D. "A virtual 3-D GIS system totally operates in a 3-D environment, but possesses all of the functionality of the traditional GIS, terrain analysis, and perspective viewing tools. GIS analysis may be performed within the 3-D environment and interactive query of the multiple attributes associated with geographic coordinates may be performed in either a 2-D or 3-D window." (Bhuamik, 1997).

Another interesting aspect of using GIS information to aid in pavement maintenance is what to do about the unexpected. Weather is somewhat predictable year in year out. There are records that can be used to determine trends and make predictions. Traffic is very similar. Predictions may then be made of what traffic volumes are going to be based on collected data and predicted growth. But what can be done about the unexpected, the events that are unpredictable? What about the unexpected earthquake or a landslide that could damage the roadway? Engineers in Lebanon developed a program to help aid in managing the unexpected. "The global landslide risk zones were interactively generated by cross-referencing and combining various data coverage. Furthermore, a historic data record of actual slope instability occurrences were compiled over three years, and was incorporated in the framework" (Sadek, 2005).

If a community is small or large, domestic or foreign roadway system, there is a need for a Pavement Maintenance System. The addition of GIS database improves access and storage of data, as compared to traditional paper based plans and records for each road. "From 1963 to the present, Altamonte Springs had accumulated more than 4,500 sheets of record drawings - a huge amount of data that needed to be centralized and better organized. The solution was an automated mapping/facilities management/geographic information system (AM/FM/GIS). This ability to centrally locate and analyze data not only makes the job of the engineer easy but the town manager or mayor when it comes to yearly budgets. One of the most important aspects of GIS is the ability for differing municipalities to share information to better allow for an overall evaluation of the road system." (Helgeson, 2002).

"Today, all transportation facilities can pull their information together in a single, common database to evaluate the total transportation infrastructure of a municipality or state, not just a single mode. The National Highway System (NHS), for example, uses GIS to look at the interconnectivity between modes to improve investment in transportation infrastructure"

(Petzold, 1994). An interesting aspect for GIS based pavement maintenance is the ability to not only enhances public roads, but specific industry related roads as well.

1.3 Statement of the Problem

There are a significant number of roadways in the U.S. and these roads need to be maintained. There are entities that have developed MIP's and have incorporated the use of GIS to track maintenance. However, there are many communities in the U.S. who do not use GIS to track maintenance. The reason may vary from lack of resources to just not knowing the different methods available to manage road maintenance. The implementation of an MIP system can assist in the management of road maintenance and reduce the cost maintaining streets.

1.4 Significance of the Problem

According to the Federal Highway Administration, in 2006, $54.2 billion was spent on maintenance and expansion of highways. The cost to communities in the U.S. to maintain pavements affects every community. With the recessionary period beginning in 2008, it is now more difficult than ever to acquire funds for road maintenance. Road degradation does not change with economic patterns and continues regardless of funding requirements. Roads start to degrade the moment they are constructed. However, with proper maintenance the life of the road can be extended. The cost to maintain a road in good condition is approximately $\$1/yd^2$. The cost to replace a road is approximately $\$75/yd^2$. There is a significant difference between maintenance and reconstruction costs. Most communities in the U.S. are currently looking for ways to manage budget shortfalls. A GIS Maintenance Improvement Plan may help reduce road construction and maintenance costs.

1.5 Scope of the Study

The City of Westfield, Indiana, has approximately 168 miles of roads including subdivisions. Up until last year the city did the maintenance of their roads by driving and evaluating once a year. The city has significant number of older country roads that have not been properly maintained. The goal of the study is to provide a solution to better maintain and manage the roads with in the city.

1.6 Purpose of the Study

A significant problem in the City of Westfield is that they do not have a long-term maintenance plan. Last year the city hired an engineering firm to develop a long term MIP. The goal was to not only to develop the MIP, but also to incorporate this plan into the city's GIS. With the information the engineering firm gathered, and the city's GIS system, the city would be better able to serve the road maintenance needs. The GIS would graphically illustrate where road maintenance dollars are going and also where they need to go.

2. Review of Literature

Pavement maintenance is not just a concern for the U.S. nor is it used only on local roads or highways. There are significant uses around the world and also for roads that may never be seen by the local resident. There were many types of programs found in the literature reviewed for this paper. Here are two interesting examples.

2.1 What Other Countries are Doing - Ireland

In Ireland, they are using GIS to track the level of service of roads along logging routes. The GIS data was then used to determine the best way to route trucks based on level of service as well as cost of repair to certain roads. "The costs assigned to the regional roads were based on routine surface maintenance, e.g. surface dressing, and were assumed to be constant over the assessment period. For a fair comparison of the designated and optimum routes, average road maintenance costs ($/m^2) were determined for respective classes of the road segments during each measuring period" (Martin, 2001).

2.2 Non-Traditional Roads – Tourism

There are many thousands of miles of National Park roads and scenic areas of the United States, which support tourism. "Fill-type failures (slides) are a concern for all mountainous roads, particularly aging roadways in National Parks and forests, many of which were constructed in the 1930s and 1940s. Commonly, progressive road-fill failures are only mitigated when collapse appears imminent, or they are repaired after catastrophic failure, and little attention is given to predicting the locations of potential future failures over a larger region" (Sas, 2008).

2.3 Advances in Technology – The Virtual World

Virtual reality (VR) can enhance the effectiveness of GIS mapping as well. The ability to interact within the map makes it more effective. "A full integration of GIS, VR and the Internet can dramatically increase GIS capacity in spatial data visualization and analysis, and extend its decision support role in applications." (Huang, 2001).

3. Procedures

3.1 Assumptions

1. Geographical Information Systems (GIS) is the best method to represent the collected data and the proposed solutions to problem. While GIS is the most powerful, it is by no means the only method. Google Earth could be used to show the data. While Google Earth and similar programs are useful, they are not quite as powerful as GIS.
2. All roads are created equal. While a road in Indiana is probably built the same way as a road in Utah there are going to be subtle differences such as materials used, soil conditions, weather etc. This study, while using referenced material from around the world, is based on the information gathered from streets in Westfield, Indiana.
3. Road conditions are many times evaluated differently by different people. VS Engineering of Indianapolis, Indiana, did the information and rating of the roads. This was their first project of this type. While it is not difficult to rate a road condition, it still requires some understanding of materials and road design. There are situations where the engineering firm rated a road and made a recommendation that differed from the city engineer evaluation. For this report, it is assumed that the engineering firm provided an accurate evaluation of the road.

3.2 Delimitations

1. The main delimitation to this project is that it based solely on data collected in Westfield, Indiana. However, once compiled, the data can be used universally to extrapolate solutions to the problems facing our transportation systems around the world.

2. There are many different ways to collect the information. Some companies use vans with sophisticated cameras to record and then evaluate the roads in the office. This system works well because you can get a tremendous amount of data quickly, but has drawbacks because the camera doesn't always tell you the whole story. This study used a simple strategy of driving, observing, and rating the road using the PASER rating on a scale from 1-10, 10 being excellent and 1 being total reconstruction of the road.

3.3 Limitations

1. Westfield is a small community of 30,000 people. There are only 68 miles of roads not including subdivisions, which make up about another 90 miles of roads. Much larger communities would result in much greater amounts of data. However if this program is successful in Westfield, it is possible that the city, county and state could use that information to better allocate funds.
2. Please see the delimitations above which add to the limitations.
3. Concerning funding, Westfield has significant budget constraints for roadway construction and maintenance. This study will show how a good Maintenance Improvement Plan (MIP) when implemented properly can help with budget concerns by planning in advance for thethose years when significant work will be necessary.

3.4 Roadway Condition Assessment

The first step is to get out and assess the existing conditions of the city's roads. The MIP would also include in the assessment of the condition of all infrastructure located within the right-of-way. This would include but is not limited to: pavement, sidewalk, storm sewer, bridges, culverts, curb & gutter, line striping, signage, and ditches. This paper will only be discussing the roadway portion.

A significant aspect of roadway maintenance is that it may be constructed from different materials each with their own unique maintenance needs. Roadways can be constructed from asphalt, concrete, brick, chip & seal, stone, or dirt. All of these roads can be found in a city. An important item in incorporating the MIP with a GIS system is that the data collection must be in a format that can be easily transferred into GIS. Collecting the road data is typically done in a spreadsheet or a database, (E.G. Microsoft Excel or Access). (Table 1 and 2)

Table 1. MIP road data collection spreadsheet

STREET	FROM	TO	SUBDIVISION	CLASS	TYPE	WIDTH	PASER	CONDITION	GIS_ID
151ST ST	LONG COVE	SETTERS		S	Asphalt	42	8	8-Good	151ST_030W_S
156TH ST	COUNT VIKING	SHINING SPRING		S	Asphalt	21	7	7-Satisfactory	156TH_230W_S
156TH ST	DITCH	TOWNE		C	Asphalt	19	6	6-Fair	156TH_500W_C
156TH ST	EVENING ROSE	SPRING MILL		S	Asphalt	24	6	6-Fair	156TH_370W_S
156TH ST	MISTY VIKING	OAK RIDGE		S	Asphalt	21	7	7-Satisfactory	156TH_290W_S
156TH ST	OAK RIDGE	COLUMBINE		S	Asphalt	21	6	6-Fair	156TH_300W_S
156TH ST	PRAIRIE CLOVER	DECLARATION		C	Asphalt	22	7	7-Satisfactory	156TH_430W_C
156TH ST	ROSEMOSS OVERMAN	EVENING ROSE		S	Asphalt	22	6	6-Fair	156TH_340W_S

Tables 1 and 2 are examples of the spreadsheet used to collect the road data. This includes the street name, the segment (from & to), if it is in a subdivision the subdivision name, the class of street (C – Collector, P - Primary, S – Secondary, L – Local), The pavement type, width, PASER rating, condition of the road and the GIS ID. Some of the cells have been hidden to make it easier to see the important data.

Table 2. MIP Road data spreadsheet with recommended repair and costs.

Street	From	To	Subdivision	PASER	Class	Type	Width	Condition	Recommended Repair	Cost
151ST ST	LONG COVE	SETTERS			S	Asphalt	42	8-Good	Preservative Seal	$2,851.00
156TH ST	COUNT VIKING	SHINING SPRING			S	Asphalt	21	7-Satisfactory	Preservative Seal	$3,100.00
156TH ST	DITCH	TOWNE		6	C	Asphalt	19	6-Fair	Preservative Seal	$5,500.00
156TH ST	EVENING ROSE	SPRING MILL		5	S	Asphalt	24	6-Fair	Preservative Seal	$1,350.00
156TH ST	MISTY VIKING	OAK RIDGE			S	Asphalt	21	7-Satisfactory	Preservative Seal	$2,250.00
156TH ST	OAK RIDGE	COLUMBINE		5	S	Asphalt	21	6-Fair	Preservative Seal	$2,100.00
156TH ST	PRAIRIE CLOVER	DECLARATION		6	C	Asphalt	22	7-Satisfactory	Preservative Seal	$1,750.00
156TH ST	ROSEMOSS OVERMAN	EVENING ROSE		5	S	Asphalt	22	6-Fair	Preservative Seal	$1,300.00

In Table 3, the typical road segment spreadsheet used by GIS is shown. The coordination that takes place between the Engineer and GIS Coordinator is that all of the road data collected by the Engineer seamlessly transfers into the GIS. The last thing the Engineer wants is data that cannot be interpreted by the GIS.

Table 3. GIS road data spreadsheet

STREET	GIS_ID	OWN	TYPE	CLASSIFICATION	CITY	ST	ZIP
E 156TH ST	156TH_230W_S	PW	STREET	Secondary Arterial	WES	IN	46074
E 156TH ST	156TH_290W_S	PW	STREET	Secondary Arterial	WES	IN	46074
E 156TH ST	156th_210W_S	PW	STREET	Secondary Arerial	WES	IN	46074
E 156TH ST	156TH_250W_S	PW	STREET	Secondary Arterial	WES	IN	46074
W 161ST ST	161ST_430W_S	PW	STREET	Secondary Arterial	WES	IN	46074
E 161ST ST	161ST_320W_S	PW	STREET	Secondary Arterial	WES	IN	46074
E 161ST ST	161ST_220W_S	PW	STREET	Secondary Arterial	WES	IN	46074

This spreadsheet is exported from the GIS database. This example only contains some of the information for simplicity sake. The key here is the GIS ID. This is what links the all the attributes of the street together. The attributes shown here are; Street Name, GIS ID, Maintenance Owner (in these cases PW = Public Works, if the street was new and still under a bond it would read BOND), Type, Classification, City, State and Zip Code.

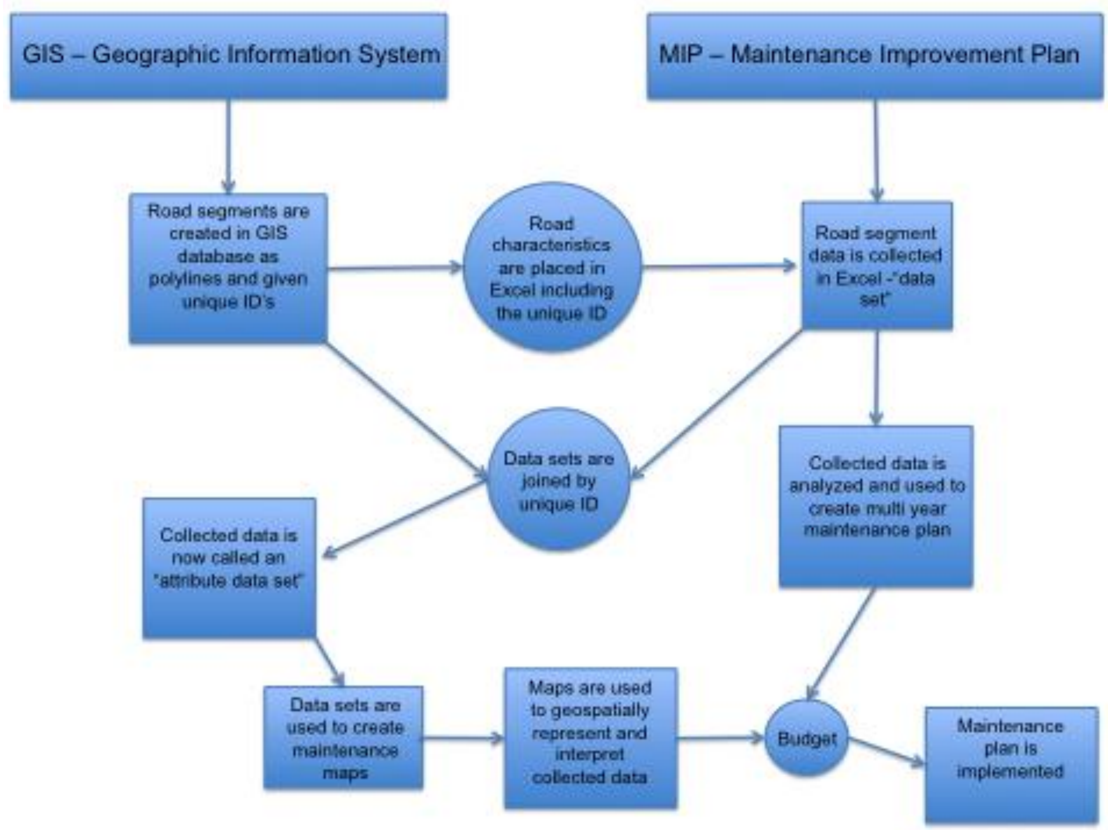

Figure 1. GIS & MIP Flow Chart

In Figure 1, the relationship between the MIP and the GIS can be seen. The key is the GIS ID, making sure that all road segments evaluated have the same GIS ID in the data collection spreadsheet as they do in the GIS

The assessment takes the greatest amount of time as well as money. The roadway data has to be gathered, analyzed, and put into a form that is organized and easy to understand. The assessment not only involves the condition of the pavement but also involves:

- **Safety** – Accident data will be analyzed as well as road geometry. Are there areas of the road that have blind turns or limited site distance? Improving the road conditions may involve lowering the speed limit or putting in traffic calming measures. The maintenance of line striping as well signage is important. There are changes being made as we speak to the reflectivity requirements of signs. Is your city aware of this and complying? Safety data can be imported into the GIS as well which allows a community see were accidents may be occurring because of road problems.

- **Volume** – The amount of traffic on a roadway will have a big effect on its life cycle. So traffic counts come into play when assessing a road. Roadways are generally classified into categories like a primary collector or arterial. The maintenance plan for a country road that gets 50 vehicles per day is not the same as a boulevard section of road that gets 40,000 vehicles per day. However the two roads have something in common, and that is they will both need maintenance starting the day they are constructed.

- **Structural Design**– Design of a roadway, like any other engineering project, needs to take into account many different factors. This can include weather, terrain, and location. A road in Arizona is not going to be built the same as a road in Alaska. Granted, the procedures are probably the same, but the materials may be very different. The differences in road design from state to state can be seen in Table 4. Roadways need to be constructed properly to include making sure the sub-grade is of adequate strength, this could include testing such as a proof roll or nuclear gauge test. The stone that is put on the sub-grade needs to be of the correct type and is sufficiently compacted. Finally, the pavement section includes proper depths and compaction of the base, binder, and surface. The engineer determines all these elements.

- **Drainage** –Proper drainage is a major factor in roadway design and maintenance. Water is one of the main enemies of pavement, especially in the winter. The freezing and thawing cycles of winter can wreak havoc on a road, causing potholes and cracking. Proper drainage is a must. Moving water away from the roadway is initially the engineer's job and includes proper slope, storm sewer design and ditch design. It then falls on the city to make sure that storm lines are clear and undamaged; ditches are clean and free from debris as well as properly maintained. "The water infiltration, freeze and thaw cycles, and repeated loadings cause the asphalt surface to deteriorate at the joint, and will eventually cause raveling. The reflective cracking will lead to structural degradation because the moisture will permeate through the cracked pavement and cause deterioration of the base and loss of support underneath the jointed concrete pavement (JCP) slabs". (Chen, 2006).All these items are evaluated when performing an MIP. This evaluation is done with the help of a rating system.

Table 4. Primary highway flexible pavement design summary (FHWA, 2006)

States	AC (mm) (inch)	Treated Base (mm) (inch)	Untreated Base (mm (inch)	Total Depth (mm) (inch)	Treated SG (mm) (inch)	Total FF[a] Depth (mm) (inch)
Alaska	130 (5)	NA	480 (19)	710 (24)	915 (36) select	1270 (50)
Idaho	165 (6.6)	NA	305 (12)	470 (18.6)	NA	470 (18.6)
Illinois	355 (14)	NA	0 (0)	355 (14)	305 (12) lime	660 (26)
Michigan	170 (6.5)	NA	710 (24)	775 (30.5)	var. gr. surf	1065-1525 (42–60)
New York	150 (6)	100 (4) ATPB	305 (12)	560 (22)	NA	560 (22)
North Carolina	265 (10.5)	NA	255 (10)	NA	NA	520 (20.5)
Ohio	203 (8)	NA	150 (6)	355 (14)	no A-4b for 915 (36)	1270 (50)
Pennsylvania	445 (17.5)	NA	0 (0)	445 (17.5)	NA	445 (17.5)

[a]FF=frost-free.

Design conditions: 30-year design; 5 million ESALs; frost-susceptible fine-grained soil with resilient modulus of 68,950 kilopascals (kPa) (10,000 pounds of force per square inch (lbf/in$^{2)}$)

3.5 Pavement Evaluation

The University of Wisconsin developed the PASER system (Table 5). PASER stands for **Pa**vement **S**urface **E**valuation and **R**ating. The rating system uses a 1 to 10 rating for the condition of the pavement, 10 being excellent 1 being failure. The PASER rating system is a good tool for evaluating roads but is in no way foolproof. For one thing it is subjective. One person using it may see a road as one rating and another person sees the roadway condition differently. However, any differences of opinion will probably not be so far off as to interfere with the proper maintenance of the road. (Figures 2-4).

Table 5. – PASER rating scale (University of Wisconsin, 2002)

Surface Rating	Visible Distress	General Condition/Treatment Measures
10 - Excellent	None.	New construction.
9 - Excellent	None.	Recent overlay. Like new.
8 - Very Good	No longitudinal cracks except reflection of paving joints. Occasional transverse cracks, widely spaced (40' or greater).	Recent sealcoat or new cold mix. Little or no maintenance required.
7 - Good	Very slight or no raveling, surface shows some traffic wear. Longitudinal cracks (open 1⁄4") due to reflection or paving joints. Transverse cracks (open 1⁄4") spaced 10' or more apart, little or slight crack raveling. No patching or very few patches in excellent condition.	First signs of aging. Maintain with routine crack filling.
6 - Good	Slight raveling (loss of fines) and traffic wear. Longitudinal cracks (open 1⁄4"– 1⁄2") due to reflective cracking. Transverse cracks (open 1⁄4") spaced 10' or more apart, little or slight crack raveling. Sight to moderate flushing or polishing. Occasional patching in good condition.	Shows signs of aging. Sound structural condition. Could extend life with sealcoat.
5 - Fair	Moderate to severe raveling (loss of fine and coarse aggregate). Longitudinal and transverse cracks (open ½") show first signs of slight raveling and secondary cracks. First signs of longitudinal cracks near pavement edge. Transverse cracking and first signs of block cracking. Slight crack raveling (open ½"). Extensive to severe flushing or polishing. Some patching or edge wedging in good condition.	Surface aging. Sound structural condition. Needs sealcoat or thin non-structural overlay (less than 2").
4 - Fair	Severe surface raveling. Multiple longitudinal and transverse cracking with slight raveling. Block cracking (over 25 - 50% of surface). Patching in fair condition. Slight rutting or distortions (1" deep or less).	Significant aging and first signs of need for strengthening. Would benefit from a structural overlay (2" or more).
3 - Poor	Closely spaced longitudinal and transverse cracks often showing raveling and crack erosion. Block cracking over 50% of surface. Some alligator cracking (less than 25% of surface). Patches in fair to poor condition. Moderate rutting or distortion (1" or 2" deep). Occasional potholes.	Needs patching and repair prior to major overlay. Milling and removal of deterioration extends the life of overlay.
2 - Very Poor	Alligator cracking (over 25% of surface). Severe distortions (over 2" deep). Extensive patching in poor condition. Potholes.	Severe deterioration. Needs reconstruction with extensive base repair. Pulverization of old pavement is effective.
1 - Failed	Severe distress with extensive loss of surface integrity.	Failed. Needs total reconstruction.

Figure 2: Rating of 9 or 10 – New road surface needs no maintenance or service.

Figure 3: Rating 6 or 7 - Some wear is occurring including some transverse or longitudinal cracking.

Figure 4: Rating 2 or 3–Block cracking over 50% of pavement with some rutting.

3.6 Maintenance Strategy

Once the evaluation has been completed and the data has been analyzed, it is time to come up with a plan, based on the ratings, which will be the most effective taking care of needed roadway maintenance. This plan must be cost effective as well as address the need for pavement maintenance (see Figure 6). No city can feasibly accomplish every maintenance task outlined in the MIP. Therefore it is important to prioritize and address the roads with the biggest problems. Cities can then delay minor maintenance needs until the following year. It is possible to use a low cost maintenance alternative until the proper maintenance can be performed. An additional item that can be done is to be cognizant of the maintenance that is reoccurring every year. Patching, line striping, ditch clearing these are all items that will be done on an annual basis. If kept track of, it becomes easier to develop strategies for routine maintenance needs. If a city can trend their routine maintenance from year to year, it allows for improved budgeting.

3.7 Roadway Improvement Prioritization

The prioritization of the roadways that require maintenance is not only based on the PASER rating but also factors like traffic volume, road classification, accident history, location in the system. You may have a road that is in desperate need of repair but only gets 20 cars a day and is a chip seal road. This would be prioritized lower than a road that gets 50,000 cars a day and only needs some minor patching. It can be hard to prioritize because there are things that cannot be seen that influence what gets done. Sometimes subjective influences are involved in the prioritization. Political districts or areas that may oppose the mayor in office may have their roads done or they may get ignored. It is up to the engineer to prioritize based on his/her experience and technical considerations.

There are many ways to repair and maintain roadways. It may not always be a one size fits all program. Because every road and road condition is different, the maintenance needs of each road are different. Just because one maintenance treatment worked on one road does not always mean it will work the same way on another.

With the maintenance plan in place and the maintenance alternatives discussed, it is now time to put the budget together and decide what maintenance will be accomplished and what maintenance will have to wait another year. A helpful tool would be something that allows tracking not only of the maintenance that has been completed in prior years but also current and future projects. The point of the MIP is not just to figure out how much money can be allocated for this year or next year's projects, but also to determine how much is needed 3-5 years down the road when looking at the pavement lifecycle chart. This is where the GIS database can be helpful. The GIS can not only keep track of what has been done, but can graphically illustrate what the maintenance needs are and maybe where the needs have been ignored or too much attention has been placed in one area.

3.8 Preliminary Cost Estimates

The cost estimate will be different every year, and will be influenced by the age and condition of roads as well weather and traffic volume. Using the prioritization and maintenance history, one can effectively budget funds for the maintenance needs of the city's roadways.

In Portugal, they use a "Decision Aid Tool (DAT) in assisting with the distribution of their Maintenance & Repair (M&R) funds for ailing roads" (Ferreira, 2009).

(a) Strategy I: corrective-only strategy involving M&R operations allocated using a minimum quality level (MQL).

(b) Strategy II: agency costs optimization approach (corrective–preventive) involving all possible M&R operations.

(c) Strategy III: agency costs and residual value of pavements optimization approach (corrective–preventive) involving all possible M&R operations.

(d) Strategy IV: total costs optimization approach (corrective–preventive).

This innovative procedure aids a more detailed way in deciding which roads get allocated the necessary funds.

Another way to look at budgeting is to look at the lifecycle of the pavement and the different fixes at each stage to decide what is financially viable. Using a pavement lifecycle chart, such as shown in Figures 5 and 6, can help illustrate the different types of maintenance needs involved with the maintenance of pavement.

As seen in Figure 6, the life costs increases dramatically if maintenance is ignored. It goes back to what was said before, “pay a little now, or pay a lot later.” Either way, maintenance or repair is inevitable. Listed below are the maintenance alternatives that can be used on road projects. All of these maintenance techniques may be used or just a portion of them based on the project.

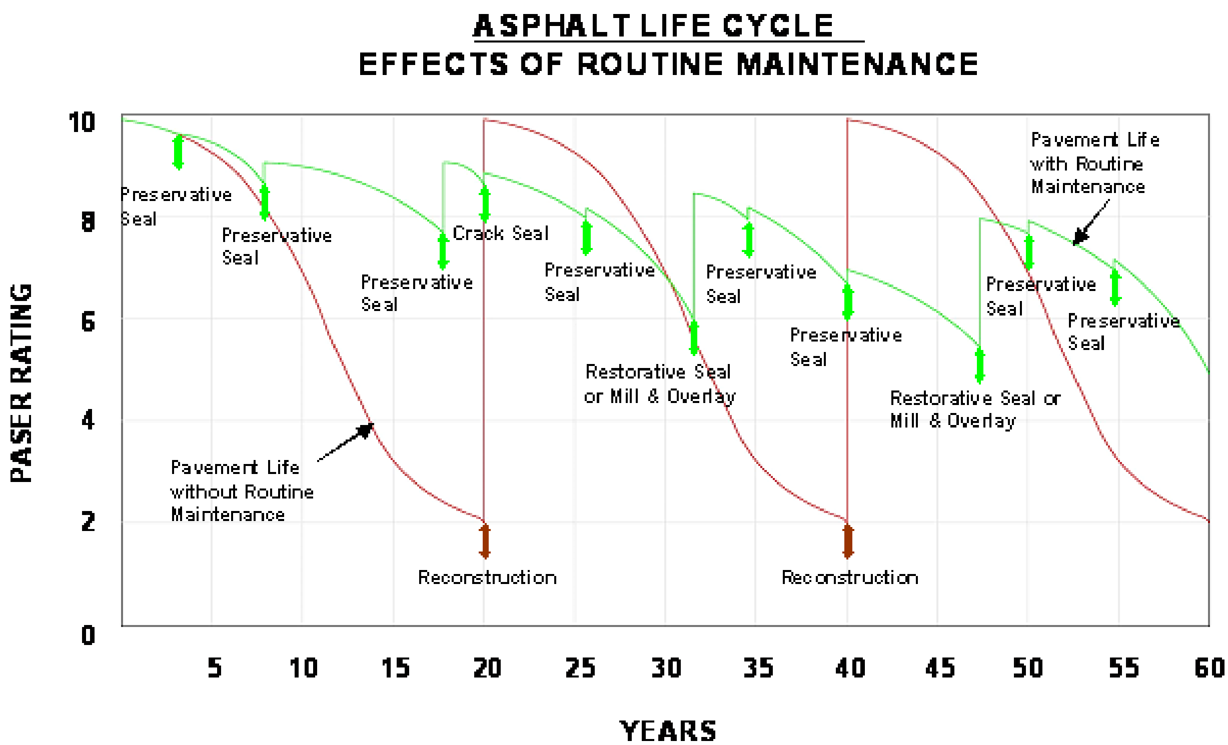

Figure 5 – Asphalt Life Cycle – Effects of Routine Maintenance

(University of Wisconsin, 2002)

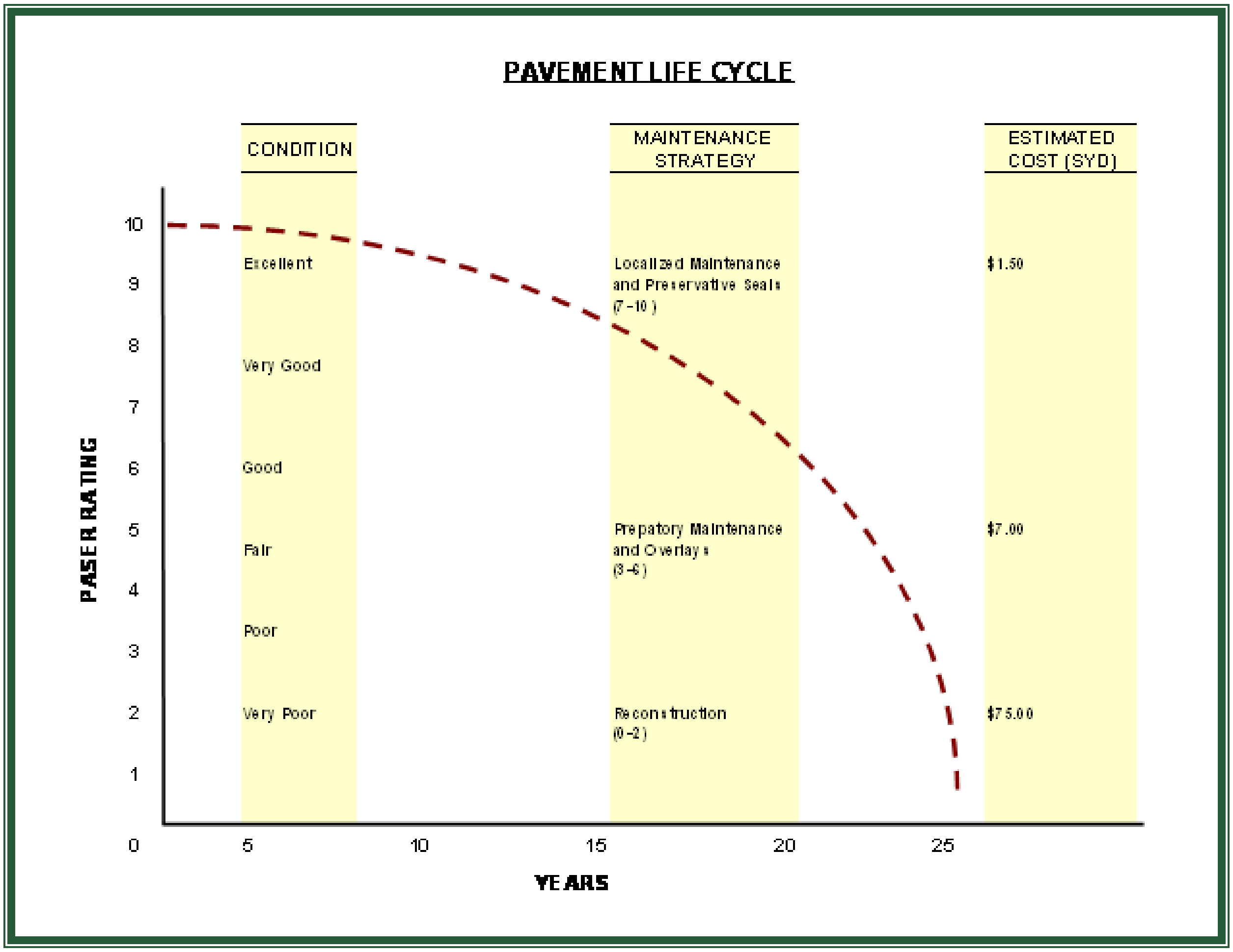

Figure 6. Pavement Life Cycle (University of Wisconsin, 2002)

3.9 Maintenance Alternatives

The following maintenance and repair alternatives are utilized in the development of the plan and budget a city will use to determine which roads get maintenance and which do not. (University of Wisconsin, 2002)

Preservative Seal – Preservative Seal is a chemical surface treatment used to soften existing asphalt pavement to prevent and repair minor pavement cracking in order to help impede the natural aging process of asphalt pavement. Preservative seal is typically used on roadways with a PASER rating ranging from 6-9. Application of seal is done about every 5-8 years depending on traffic volume, type of traffic, and weather conditions.

Restorative Seal – Restorative Seal is a chemical surface treatment containing liquid asphalt used to soften existing asphalt pavement to prevent and repair minor pavement cracking up to 3/8 inch wide in order to help impede the natural aging process of asphalt pavement. Restorative seal is typically used on roadways with a PASER rating ranging from 3-6.

Crack Seal – Crack Seal is used to fill cracks in pavements greater than 3/8 inch wide to minimize the amount of moisture migrating into and deteriorating the pavement sub-grade. Crack seal is typically used on roadways with a PASER rating ranging from 4-6.

Surface Milling – Surface Milling is used to remove existing asphalt or concrete partial depth or full depth to promote positive drainage, establish or re-establish a desired profile grade, create a square joint for a desired interface with new pavement, create a water stop for a pavement patch or to completely remove a section of pavement for patching.

Base Repair – Base Repair is used in conjunction with a full depth pavement patch when there is a relatively low frequency of base failure as a percentage of the entire road. The failed pavement area is removed to sub-grade elevation; the sub-grade is removed until stable material is encountered (minimum 1.5 Tons per square foot); pavement materials areinstalled in compacted lifts. In some cases, sub-grade stabilization may be utilized in lieu of excavating to stable sub-grade material.

Sealcoat – Sealcoat (Chip and Seal) is used to seal a fractured roadway, restore surface friction to an existing roadway, to stabilize an aggregate roadway or shoulder, as a dust palliative on an aggregate roadway, and or to delineate the shoulder versus the roadway. Crack seal is typically used on roadways with a PASER rating ranging from 4-6.

Full Depth Reclamation – Reclamation or recycling is used to reconstruct failed pavement, where the majority of the pavement has failed over a high percentage of the pavement area, for a significant distance of usually a half-mile minimum. This process is often used to reconstruct existing pavement sections that also require widening, as recycling is conducive to preparing the areas to be widened by spreading of the recycled materials uniformly over the existing pavement area and the areas to be widened at the same time. Recycling eliminates the cost of demolition, removal and hauling away of the existing failed pavement. Cost for reclamation is about $3/yd^2 vs. $7-10/yd^2 for full depth reclamation. Additionally, the treatment of the existing material for use in-place is less expensive than purchasing, hauling and placement of new material. Other benefits to this method are the ability to remove excess material to reclaim and reuse existing curbs, to promote positive drainage, and/or establish or re-establish a desired profile grade. Full depth reclamation differs from reconstruction in that it doesn't replace the existing base. Removing soft area and replacing with stone would fix any soft spots found in the base.

Resurfacing – Resurfacing is used to provide a new wearing surface over a structurally sound pavement; to seal a fractured, but structurally sound pavement; to establish or re-establish a desired profile grade; or to provide positive drainage. A resurfacing course is generally 1-1.5 inches thick.

Reconstruction – Reconstruction involves the total removal of the existing pavement and aggregate base as required due to extensive sub-grade failure. The cross section of the new roadway should be in accordance with the thoroughfare plan or roadway functional classification. Reconstruction differs from Full Depth Reclamation in that the base is left in place. The exception would be if there are soft areas in the base, those would be removed and replaced with stone.

Widening – Widening is done where the existing roadway lane widths do not meet desired standards, to improve turning radii, to improve other areas where traffic regularly leaves the paved area due to undesirable geometrics or other negative conditions, or to provide a paved shoulder. The new pavement section width is to be determined by the thoroughfare plan for the associated road type encountered.

Curb Removal & Replacement – Curb replacement is done where the existing curb is damaged and no longer adequately performs its intended function(s) as a drainage conveyor and/or a roadway barrier.

Sidewalk Removal & Replacement – Sidewalk is replaced where the existing sidewalk no longer meets standards for curb ramps, grade, width and/or smoothness.

Pavement Marking and Striping – Pavement markings are restriped where fading has occurred over time and limited visibility of the markings may result in safety hazards for motorists and pedestrians.

Grading – Grading is used to create and or restore positive drainage away from the edge of pavement or edge of shoulder; or to create or restore the shoulder adjacent to the edge of pavement; or to promote positive drainage within existing ditches.

Mulched Seeding – Mulched Seeding is placed where the earth adjacent to pavement areas has been disturbed do to snow plowing operations, grading for drainage or other maintenance procedures for pavement or appurtenances.

Tree Trimming/Removal – Tree trimming and/or removal along the roadway edge is desirable as leaves that fall and remain on the road will decompose and release acids that slowly break down the asphalt.

3.10 Specific GIS Procedures

3.11GIS ID's and Data Sets

GIS is based on data that represents anything from the road properties to storm sewer pipes. These different types of data are called attributes. Attributes make up the pipe or roadway. They can be the length, width, age, material, etc. These attributes are the information attributed to the item you are looking at. The complete set of attributes is what is called a data set. An object can have multiple data sets associated with it. A data set is graphically represented as a line (e.g., a section of road) a point (e.g., a property corner), a polygon (e.g., a sanitary sewer lid). These data sets can be different colors or line types similar to what one would find in AutoCAD. What links them together is the GIS ID. The ID is like the spiral binding of a notebook. The pages of the notebook are different data sets that are linked by the GIS ID. A road segment from one intersection to another would have a GIS ID. Then the entire associated infrastructure would make up the associated data set. A road segment that has its own GIS ID can be linked to a storm sewer that has another id the two can be brought together in what is called a merge. It is a merging of the two data sets that are associated with the GIS ID. This can be complicated when multiple objects are associated.

The GIS ID that identifies the road segment is similar to the spiral binding and the attributes i.e., pavement type, width of road, segment length, line striping, etc are the pages in the notebook. The GIS ID is the key to linking all the data together. This information or attributes is what the person evaluating the road collects in the field. These attributes are collected in a spreadsheet developed by the GIS coordinator so as to seamlessly flow into the GIS database. It is recommended that the GIS coordinator sit down with the engineer to make sure that they are both on the same page when it comes to the data that needs to be collected and the fashion in which it is collected. The last thing the engineer wants is to collect a significant amount of data that cannot be placed into the GIS.

3.12 Verify and Visually Represent Collected Data

Once the data is collected it is a good idea to verify it. Make sure that the segment lengths are the same as the data collected length. This can identify not only a possible problem in the collected data but also a problem in the existing data. This may seem to be a tedious and unnecessary task, but it is better to check the data in the gathering stage than having to go through everything multiple times due to mistakes. Once the data is placed in the GIS database, it can be manipulated graphically. A certain color and line type can be used for a resurfacing project, another line type and color can be used to represent full depth reclamation. A polygon can be used to represent a full depth patch. The dimensions and location of the patch become attributes, and can be sought out when the time comes to do an estimate for that patch. (See Figure 7)

Nothing is worse than collecting the patch information, marking the pavement area that needs to be patched, and then when you go to do the estimate the paint is gone and you are not able to remember the dimensions or the location. All this data will be in the GIS database.

It can be easily accessed, and in conjunction with the MIP spreadsheet that was used to collect the data, can be used to develop a plan and budget for the fiscal years road maintenance needs.

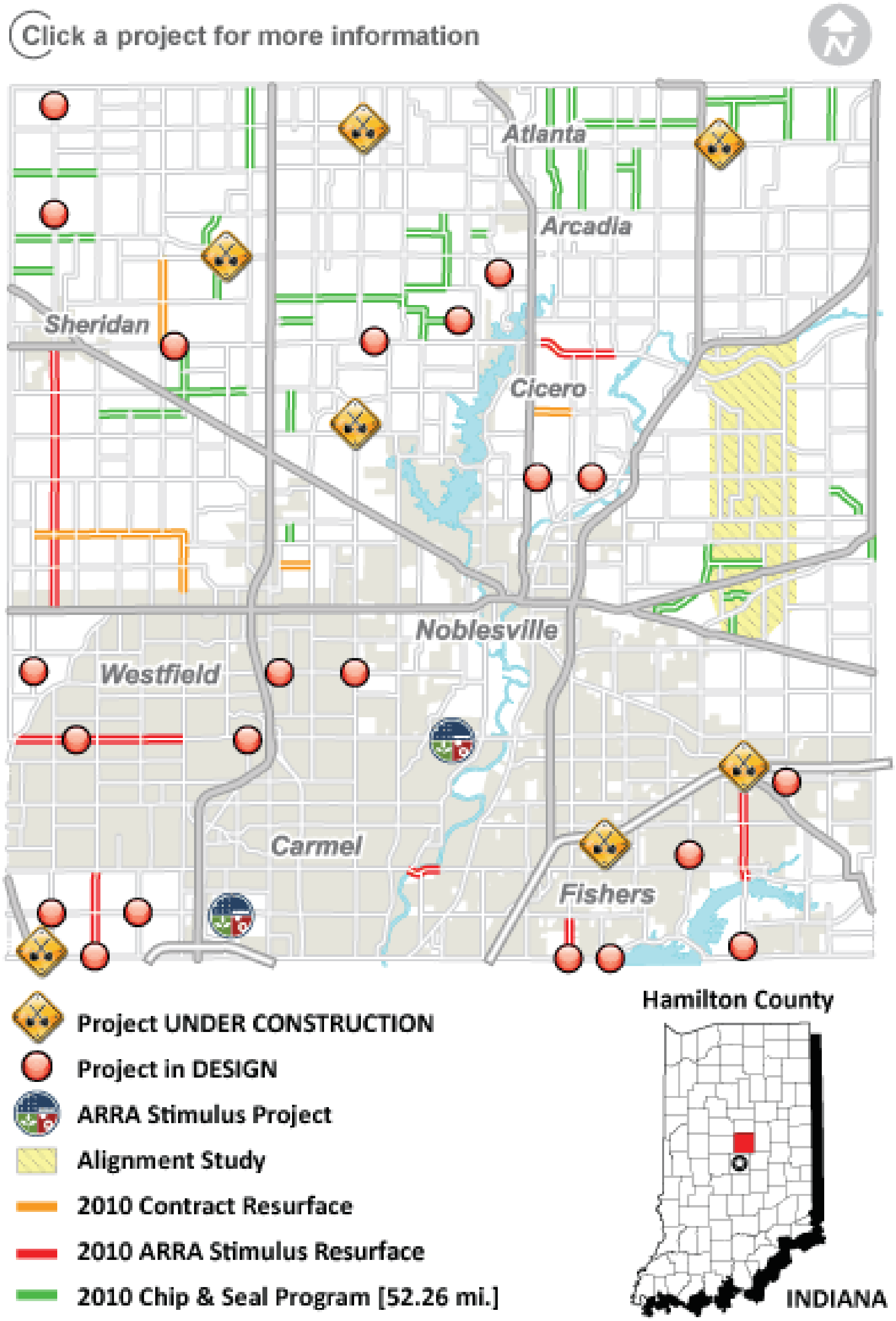

Figure 7 – Hamilton County, Indiana Project Map

(Hamilton County Indiana, 2011)

3.13 Data Now and in the Future

Current data becomes reference material for the future, not only for a single community, but for adjacent communities as well. There is a trend now for counties and the communities that reside within them to share data and to come up with countywide projects that are including local community's road maintenance needs. The City of Westfield, Indiana, coordinates with the other communities in Hamilton County when they do their line striping and chip sealing every year. The County bids out the line striping for all of Hamilton County and the city sees a nice reduction (approximately 30%) in the unit price when they combine their line striping needs with those of the rest of the county. When the City of Westfield does their chip seal roads, they let the county do them because the county has 5 times the length of roads of the city and can get better unit pricing.

It just makes economic sense to combine projects when it comes to road maintenance. Every community is going to perform some maintenance. Smaller communities need to effectively use their budgets; there is an opportunity for cost savings when partnering with other communities. This will lead to better roads because more maintenance can be accomplished every year. This will in turn lead to less taxpayer dollars being needed for roadway maintenance and could be used to improve things like capacity and safety.

4. Findings

The collection and evaluation of the City of Westfield's 168 miles of roads took approximately eight months to complete. This included approximately three months of data collection, three months of analyzing the data and two months to produce a workable MIP. This was all done with the cooperation of VS Engineering of Indianapolis, Indiana and the City of Westfield, Indiana to include the Engineering department as well as the GIS department. From the report it was determined that the Cities streets were in good condition (see figure 8) with over 80% of the roads having a PASER rating of 6 or higher.

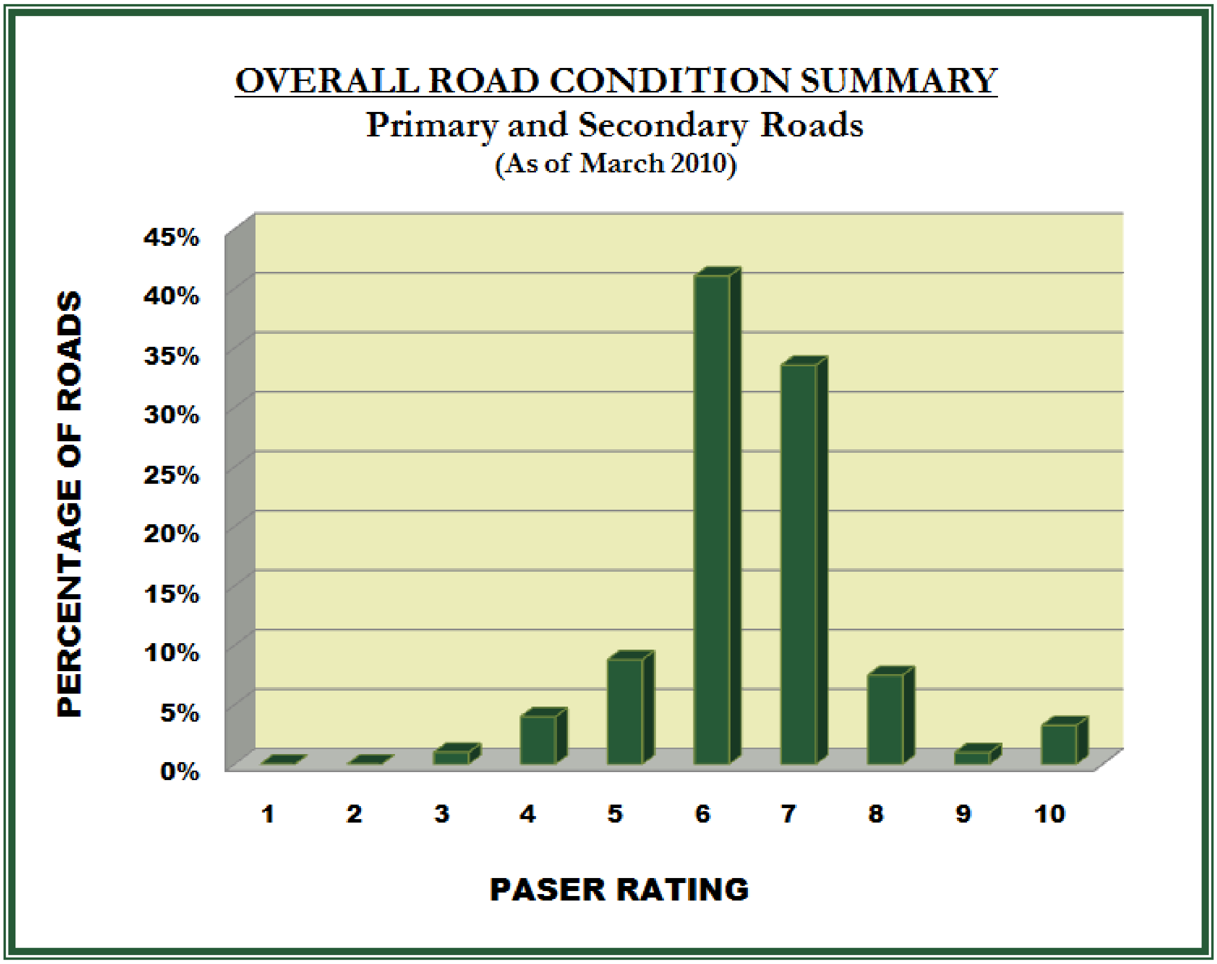

Figure 8 – Overall rating of primary and secondary roads in Westfield. (VS Engineering, 2010)

In Table 6, the yearly maintenance costs are shown for each road segment. The cost shown is only an estimate. It is based on the assessment from a year ago and should be updated every year. In the year columns you can see the expected total cost of maintenance work to be done for that year. You can see that some years are a lot higher than others. This is due to the MIP being implemented this year. The initial costs are always high due to "playing catch-up" with maintenance. These costs may go up or down due to the shown amounts being estimates based on existing road conditions.

Table 6. Road segment yearly cost estimate (VS Engineering, 2010)

Street	From	To	Year 2010, Priority 1 & 2	Year 2011, Priority 3	Year 2012, Priority 4	Year 2013, Priority 5	Year 2014, Priority 6	FUTURE
			$467,925	$388,512	$36,818	$173,301	$187,619	$1,154,171
151ST ST	LONG COVE	SETTERS	$10,123					$5,627
156TH ST	COUNT VIKING	SHINING SPRING						$1,801
156TH ST	DITCH	TOWNE		$23,100			$13,780	
156TH ST	EVENING ROSE	SPRING MILL	$15,000			$4,428		
156TH ST	MISTY VIKING	OAK RIDGE		$3,500				$919
156TH ST	OAK RIDGE	COLUMBINE				$767		
156TH ST	PRAIRIE CLOVER	DECLARATION					$6,794	
156TH ST	ROSEMOSS OVERMAN	EVENING ROSE				$5,760		

These figures would also differ depending on the age of the roads. If a city has a lot of new roads and did a good job maintaining their older roads this table may look differently, with lower costs in the early schedule and steadily going up.

The key is to look for patterns in the plan. This will help in determining what type of maintenance will be needed in the future. This is an example where the GIS makesthe task easier. The GIS makes it easier to see trends in maintenance because the maintenance data is not just dollar amounts in a spreadsheet but maintenance needs are graphically represented, as well. A trouble spot may not necessarily be where the highest costs are. A trouble spot may be where the same maintenance is done year after year. For example, a patch that is replaced each year. The GIS and the MIP work hand in hand to give the city a way to efficiently and cost effectively do road maintenance.

5. Conclusion

GIS based pavement maintenance is the future for managing infrastructure maintenance. If it can be used for roads, it can be used for sanitary sewer mains, storm sewers or any other utility or system. It will improve the quality of our infrastructure, reduce costs and provide an ever improving system to the citizens it affects. The combination of a powerful tool like GIS and Pavement Data Collection will, "enhance the entire process of pavement management from pavement condition data collection and recording to the prioritization of pavement segments for rehabilitation." (Bandara, 2000). In addition, GIS, "with their spatial analysis capabilities, match the geographical nature of the road networks, they are considered to be the most appropriate tools to enhance pavement management operations, with features such as graphical display of pavement condition." (Parida, 2005).

The use of GIS will be used to "predict future conditions"(Goulias, 2000)(Johnson, 1994) and allow us to plan far into the future. One of the main goals with using GIS is not only the data aspect, but the cost prediction. With accurate data, budgets can be done more accurately and allow for planning to help "prevent widespread deterioration"(Vandermost, 2006) of roadway infrastructure. "Among the significant improvements expected in PMSs in the next 10 years are improved linkage among, and better access to, databases; systematic updating of pavement performance prediction models by using data from ongoing pavement condition surveys; seamless integration of the multiple management systems of interest to a transportation organization; greater use of GIS and GPS; increasing use of imaging and scanning and automatic interpretation technologies; and extensive use of formal optimization methods to make the best use of limited resources." (Kulkarni, 2003).

There is no magic formula to accurately predict how long a road will last. The more data that can be gathered the better our roadways will be and the easier it will be to maintain them. More importantly, help save taxpayer money while improving our roadways.

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