1.0 KILLEEN, TX.
PAVEMENT MANAGEMENT SYSTEM REPORT

1.1 PROJECT INTRODUCTION

The nation's highways represent an investment of billions of dollars by local, state and federal governments. For Killeen, who maintains **495** miles of paved roadways, this investment translates into roughly $644.0M, when factoring in a replacement (reconstruction) cost of approximately $1.3 million per mile.

Total Pavement Network Value ($)	**$643.5M**
Total Distress Value/"Fix" Everything ($)	**$16.7M**

1.2 PRINCIPLES OF PAVEMENT MANAGEMENT

Given the persistent shortage of funds for maintaining these street systems, the preservation and stewardship of existing roads have become a major activity for all levels of government. An excellent way of maximizing the return on investment for the monies that do exist for road maintenance is to implement a pavement management system.

In its most basic form, pavement management is a systematic, heads-up approach to extending the life of your pavement network. More specifically, it is the process of planning, budgeting, funding, designing, constructing, monitoring, evaluating, maintaining and rehabilitating the pavement network to provide maximum benefits with available funds.

A pavement management system provides tools and methods for finding and implementing the best strategies to keep your pavements up and running as smoothly and efficiently as possible, and for as long as possible. Repairing streets when they are still in fair condition ultimately costs less over their lifetime than waiting to fix roads that have fallen into poor condition. In other words, the proactive approach of routine pavement management means less money wasted on frequent roadway reconstruction, and a potential savings of millions of dollars to your community.

This process is illustrated in **Figure 1-1**. It details how timely intervention can delay the inevitable total reconstruction for as long as practical. If repairs are delayed until a road is rated in "Fair" condition or worse, the cost of rehabilitation becomes 4 to 5 times more expensive than for those roads in "Good" condition. This means without preventive pavement maintenance, the cost of rehabilitation will be prohibitively expensive.

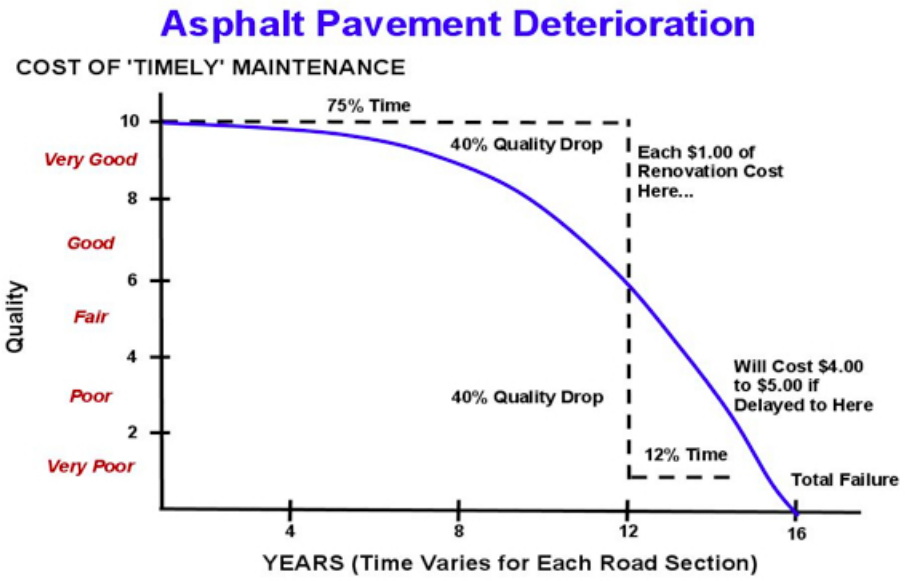


Figure 1-1 - Pavement Life Cycle Curve

Practically speaking, pavement management systems provide a way to store an accurate inventory of all roadways your agency is responsible for, enriched with links to easements, as-built records and historical documentation. The breadth and depth of information they hold, including digital images of roadways, baseline pavement condition data and reviews of deterioration over time, make them invaluable resources for measuring and tracking the effectiveness of maintenance and rehabilitation strategies.

It seems self evident that staying on top of the condition of your roadways will save you money and time. Successful pavement management programs let agency decision makers develop reliable performance models for the roadway, which can be used to generate sound policies and long-term rehabilitation strategies, budgets and timetables. Pavement management also acts as a central registry of the roadway network that can be shared with other agencies for issues related to right-of-way assets.

Of course, another compelling reason for implementing a pavement management system is the Governmental Accounting Standards Board (GASB) Statement 34. This regulation requires agencies that collect taxes for the purpose of managing a long-term, fixed infrastructure asset to either:

- **Option #1** - Implement financial accounting controls to effectively depreciate and plan for the replacement of fixed assets; or,
- **Option #2** - Implement an asset management system that provides a mechanism to gauge and budget for the long-term rehabilitation and/or maintenance of assets.

This study completed on the City's roadway network can be used as the basis for achieving GASB 34** compliance, either as the foundation for the inventory and valuation of the network (Option #1), or as the foundation of an asset management system (Option #2).

** Although the City may not be required to meet GASB 34 standards, they should still follow the industry best practices with regards to monitoring their infrastructure.

1.3 THE PAVEMENT MANAGEMENT PROCESS

Figure 1-2 depicts the three unique, but equally important steps that comprise the pavement management process.

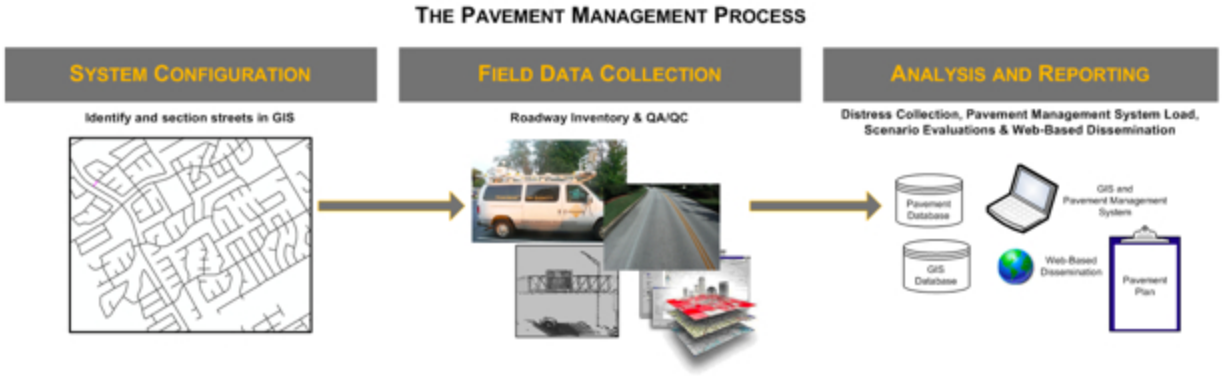


Figure 1-2 - The Pavement Management Process

1. System Configuration

The first step involves identifying all roadways of the project network and assigning them a unique identifier. For each asset, we listed its physical characteristics (length, width, etc.) and attributes such as pavement type and road classification. As part of this step, the network is linked to a map.

2. Field Data Collection or Field Surveys

After Step 1 is completed, every roadway in the system is surveyed and its condition assessed using the following criteria:

Surface Distress

Using high definition digital images, technicians evaluate the distress of the roads they travel on. They record pavement conditions such as cracking, potholes and raveling, all of which are examples of surface distress.

Severity

Once a distress has been identified, its severity (Low, Moderate, High) is attached to the appropriate record and its count (e.g. number of potholes), square footage (area covered by cracking), or linear feet (length of a specific crack) is added, as well.

All field survey data is collected in samples and summarized on an intersection-by-intersection basis. Each section constitutes a unit of data to populate the pavement management system.

Other data collected during field surveys include the pavement width, the pavement type, GPS coordinates and digital images.

3. Analysis and Reporting

After all of the data has been gathered in the field, PCIs are calculated using the following process:

Step 1: All condition ratings of the field surveys captured at sample areas are combined to calculate one value that represents the whole section (section PCI) using the area weighted average:

$$PCI_s = PCI_r = \frac{\sum_{i=1}^{R} PCI_{ri} \times A_{ri}}{\sum_{i=1}^{R} A_{ri}}$$

Where

PCI_s = PCI of a pavement section

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

PCI_{ri} = PCI of random sample unit number i

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

R = total number of inspected random sample units

Step 2: If additional sample units are inspected, they can be used to enhance the section PCI as follows:

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

$$PCI_s = \frac{PCI_r(A_s - \sum_{i=1}^{A} A_{ai}) + PCI_a \times \sum_{i=1}^{A} A_{ai}}{A_s}$$

PCI_a = area weighted average PCI of additional sample units

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

A_{ai} = area of additional sample unit *i*

A_s = total section area

Step 3: Using customer-defined constraints, such as the desired level of service or available rehabilitation technologies or budgets, paving plans are developed in the pavement management system.

1.4 UNDERSTANDING THE PAVEMENT CONDITION INDEX

The following illustration (Figure 1-3) shows how the Pavement Condition Index (PCI) deteriorates over time for 3 different types of roadways. It also compares the PCI's to commonly used descriptive terms (Good, Satisfactory, Fair, Poor, Very Poor, Serious, Failed). The divisions between the descriptive terms are not fixed, but are meant to indicate common perceptions of roadway condition.

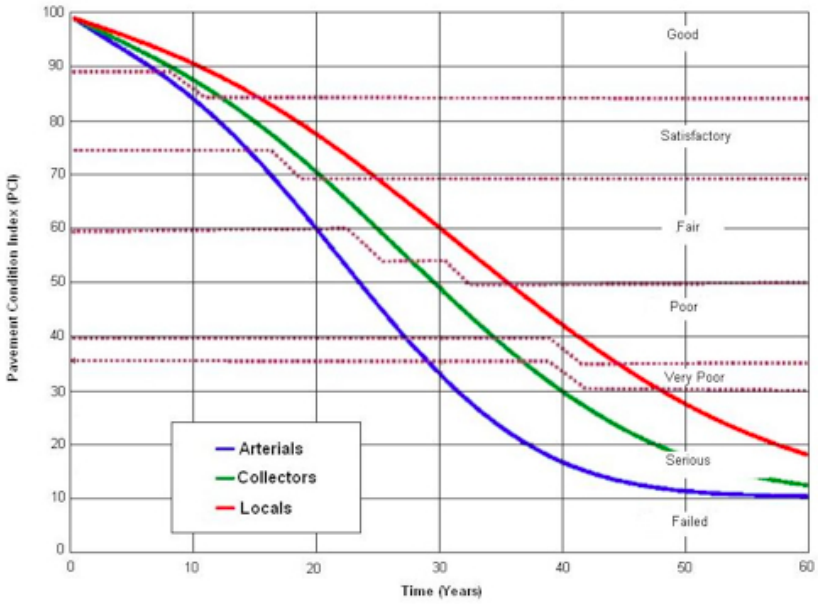


Figure 1-3 - Understanding the Pavement Condition Index Score

Table 1-1, an industry standard, defines the different PCI condition levels with respect to the remaining life of a pavement and typical rehabilitation options recommended.

PCI	Work Type	Description	Remaining Life	Rehabilitation Options
86-100	Rejuvenation	Good	15-25 Years	Little or no maintenance required - reclamite, fog seal rejuvenation
71-85	Global Preventative Maintenance	Satisfactory	12-20 Years	Routine maintenance - microsurfacing, slurry seal, crack sealing
51-70	Critical Condition	Fair	10-15 Years	Cape seals, microsurfacing, thin overlays
26-50	Conventional Approach	Poor	7-12 Years	Resurface, mill and resurface
0-25	Reconstruction	Very Poor	5-10 Years	Reconstruction, rebuild, full depth reclamation

Table 1-1 - Industry Standard for PCI Condition Levels

2.0 FIELD DATA COLLECTION

2.1 PAVEMENT SURFACE CONDITION SURVEY

At the heart of pavement management is the acquisition and processing of pavement performance data. Transmap collected these data for Killeen using GPS and high definition digital images for each road section.

Pavement distresses recorded during this survey are itemized in Table 2-1 below, with respect to their pavement type (AC=Asphalt Concrete Pavement, PCC=Portland Cement Concrete).

Index	Description	Applied To
Asphalt		
Surface Distress (SD)	**Fatigue cracking that consists of a series of interconnecting cracks formed by repeated traffic loading**	**AC**
	An assessment of the number and quality of roadway patches	**AC**
	An assessment of number of potholes and severity	**AC**
	Measurement of longitudinal cracks quantified by 3 severities and lengths	**AC**
	Measurement of transverse cracks quantified by 3 severities and crack count	**AC**
	Measurement of extent and severity of alligator cracking	**AC**
	Measurement of the extent of weathered and raveled pavement	**AC**
	Measurement of extent and severity of block cracking	**AC**
Concrete		
	Edges of slabs broken	**PCC**
	Patching present in concrete	**PCC**
	Slabs divided into four or more pieces	**PCC**
	Transverse/longitudinal cracks that are divided into two or more pieces	**PCC**

Table 2-1 - Description of Distresses Recorded by Transmap

2.2 PAVEMENT SECTIONS INVESTIGATED

The intent of this study was to develop a network-level pavement management system for the paved and inspected roadways of Killeen. When the survey was conducted in July 2013, the network was comprised of approximately **495** centerline miles of roadway, broken down into three groups. The three groups are: Arterials, collectors, and residential. Table 2-2 summarizes the information regarding the network.

Functional Class	Length (Miles)	Area (yd²)	Percentage (Area)	Weighted Average PCI
Arterial	43	1,196,867	13%	84.65
Collectors	47	969,402	10%	82.75
Residential	405	7,186,645	77%	83.51
Totals	495	9,352,914	100%	

Table 2-2 Total Inspected Area and Percentages

The network can be broken down into three groups of interest: Those streets classified as arterials, those classified as collectors, and the remaining streets classified as residential. The bar graph below shows the number of square yards for each group and the related PCI's. The average PCI for the the three groups is very similar. The pavement surface area of the residential streets is almost six (6) times as great as the arterial group.

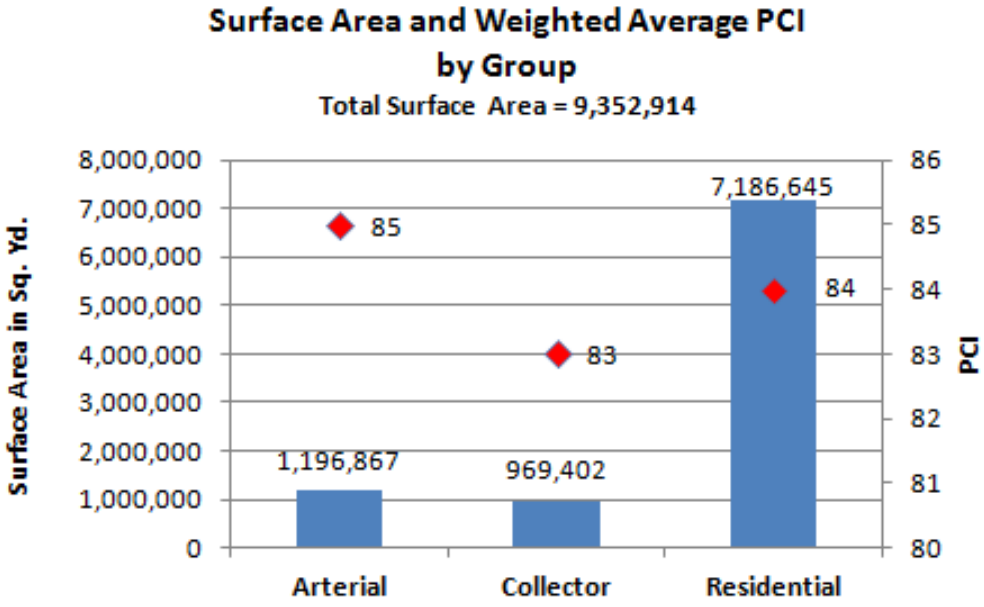


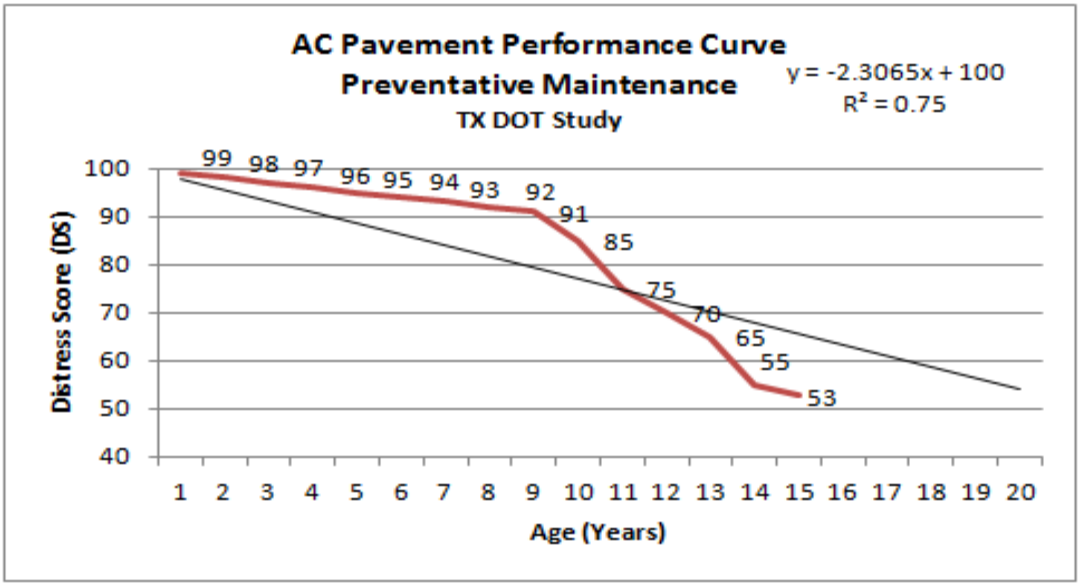
Figure 2-2 - Pavement Surface Area and Average PCI by Group

3.0 PAVED NETWORK CONDITION & FINDINGS

3.1 PAVED NETWORK PRESENT CONDITION

The street network maintained by Killeen consists of approximately 495 centerline miles of pavement, with a weighted average PCI for 2013 of **84**. The condition was obtained by multiplying the pavement condition score of each roadway segment by the area of each segment, and then dividing the product by the total square feet of the entire roadway network. (Section 1.3).

Figure 3-1 shows how the average condition index will deteriorate over time, if no preventive maintenance measures are taken. For example, in five years it is estimated that the average PCI will drop from 84 to 75. On average, the annual PCI drop for Killeen is estimated to be 2.0 points per year.



Recommend using a 2.0 drop per year

Figure 3-1: The "Do Nothing" approach will lead to a substantial drop in the average PCI of the network.

Recommended Pavement Performance PCI Drops by M&R Category

Transmap recommends using an average of the APWA/MicroPAVER model and the Texas DOT linear equation as shown above for PCI drops for each M&R Category. The averages are shown in the last column in the table below.

M&R Category	PCI Range	APWA & PCI Family Only	Transmap Recommendation Average of APWA, PCI, and Linear
Rejuvenation	86-100	1.5	**1.75**
Global	61-85	1.27	**1.79**
Conventional	40-60	2.5	**2.41**
Reconstruction	0-39	3.25	**3.25**

3.2 RECONSTRUCTION BACKLOG

Backlog roadways are those that have dropped sufficiently in quality such that surface-based rehabilitation efforts would no longer be cost efficient. They require partial or total reconstruction. Backlog is expressed as the percentage of roads requiring partial or full reconstruction as compared to the total network.

The concept of present condition or PCI score and backlog must be fully understood in order to develop an effective pavement management program. The PCI score indicates the pavement condition and represents the amount of equity in the system. It is the value most commonly considered when gauging the pavement quality of a roadway network. It may also be used to define a desired level of service – that is, an agency may wish to develop a pavement management program such that in 5 years the pavement network score meets a set minimum value. It is the backlog, however, that defines the amount of work an agency is facing and is willing to accept in the future. Furthermore, it is the combination of the two that presents a true picture of the condition of a roadway network, and conversely defines improvement goals.

Generally, a backlog of 10% to 15% of the overall network by area is considered acceptable and manageable from a funding point of view. A target value of 12% would be considered ideal. A backlog below 10%, while certainly desirable from a service perspective, may represent a non-optimal expenditure of funds, if rehabilitation dollars are limited. Backlogs approaching 20% or more tend to snowball rapidly, unless aggressively checked through larger rehabilitation programs.

Figure 4-3 shows the percentage of surface area in each Maintenance & Rehabilitation (M&R) Category for 2013. Sections that will be considered for Killeen's backlog fall into the Reconstruction M&R Category.

With only 30,828 square yards of the surface area in the backlog category, the City staff is doing an excellent job of keeping the network in or above the Global M&R Category. Roads in the Global Category require preventative maintenance, which could include patching, cape seal, micro surfacing, double micro surfacing, crack sealing or liquid road. If left untreated, these roadways will drop in quality and become overlay candidates.

If there is no maintenance performed on the network, over the next five years, in 2018 this surface area will increase to 73,826 square yards or 1% of the network total. The pavement segments represented by this category need to be considered for the City's worst-first reconstruction candidates.

Total Network for 2013 by M&R Category

M&R Cat	PCI	Sq. Yd.	Sq. Yd. %	Mile	Unit Cost	2013 Cost
Rejuvenation	86-100	4,872,455	52%	250.56	$0.00	$0
Global	61-85	4,284,420	46%	234.45	$3.16	$13,538,767
Conventional	40-60	165,211	2%	8.88	$14.50	$2,395,560
Reconstruction	0-39	30,828	0%	1.52	$27.00	$832,356
Total		**9,352,914**		**495.41**		**$16,766,683**

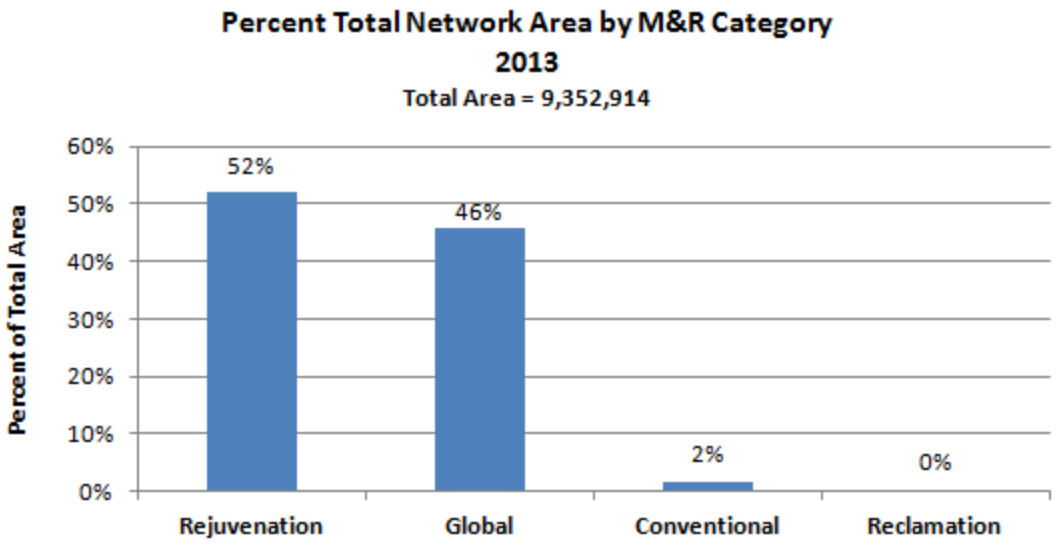


Figure 4-3: Total Network -Percent Total Area by M&R Categories in 2013

Arterial Network for 2013 by M&R Category

M&R Cat.	PCI	Sq. Yd.	Sq. Yd. %	Mile	Unit Cost	2013 Cost
Rejuvenation	86-100	622,260	52%	20.9	$0.00	$0
Global	61-85	549,386	46%	20.97	$3.16	$1,736,060
Conventional	40-60	25,221	2%	0.97	$14.50	$365,705
Reconstruction	0-39	0	0%	0	$27.00	$0
		1,196,867		42.84		$2,101,765

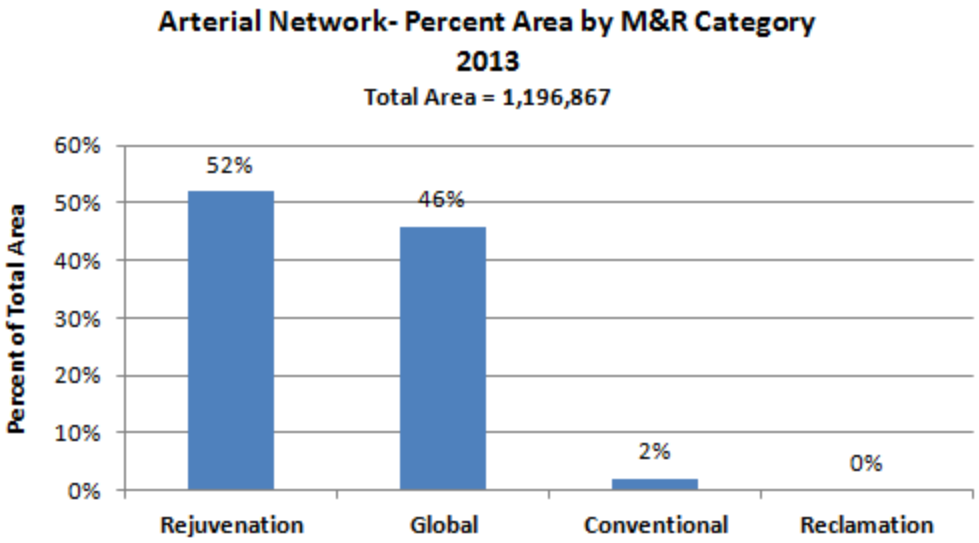


Figure 4-4: Arterial Network - Percent Total Area by M&R Categories in 2013

Collector Network for 2013 by M&R Category

M&R Cat.	PCI	Sq. Yd.	Sq. Yd. %	Mile	Unit Cost	2013 Cost
Rejuvenation	86-100	453,915	47%	21.12	$0.00	$0
Global	61-85	498,198	51%	25.22	$3.16	$1,574,306
Conventional	40-60	16,073	2%	0.76	$14.50	$233,059
Reclamation	0-39	1,216	0%	0.07	$27.00	$32,832
		969,402	1	47.17		$1,840,197

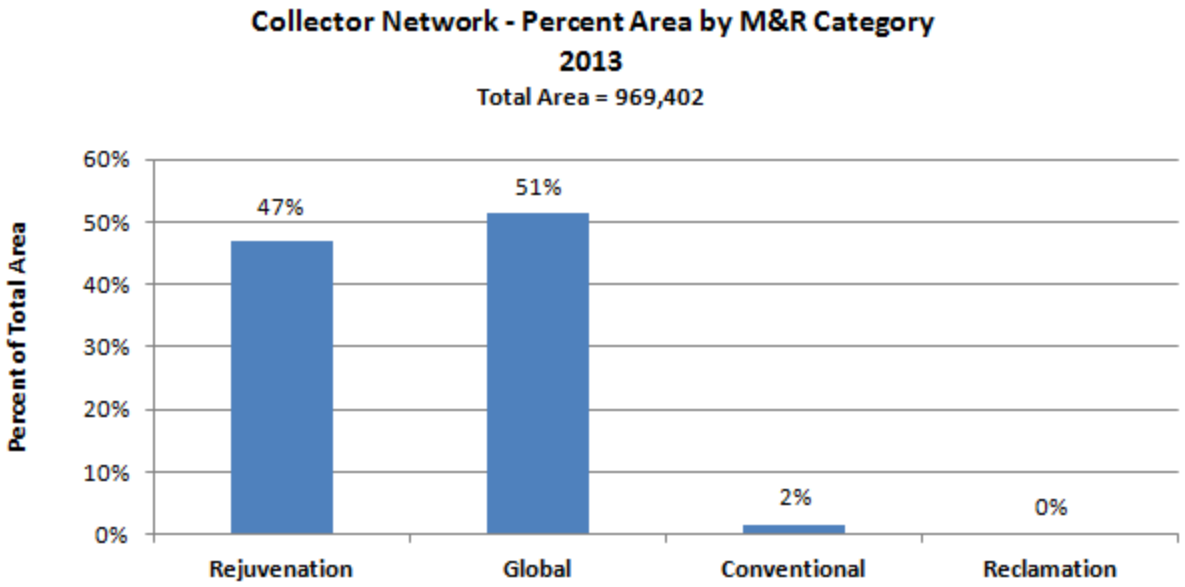
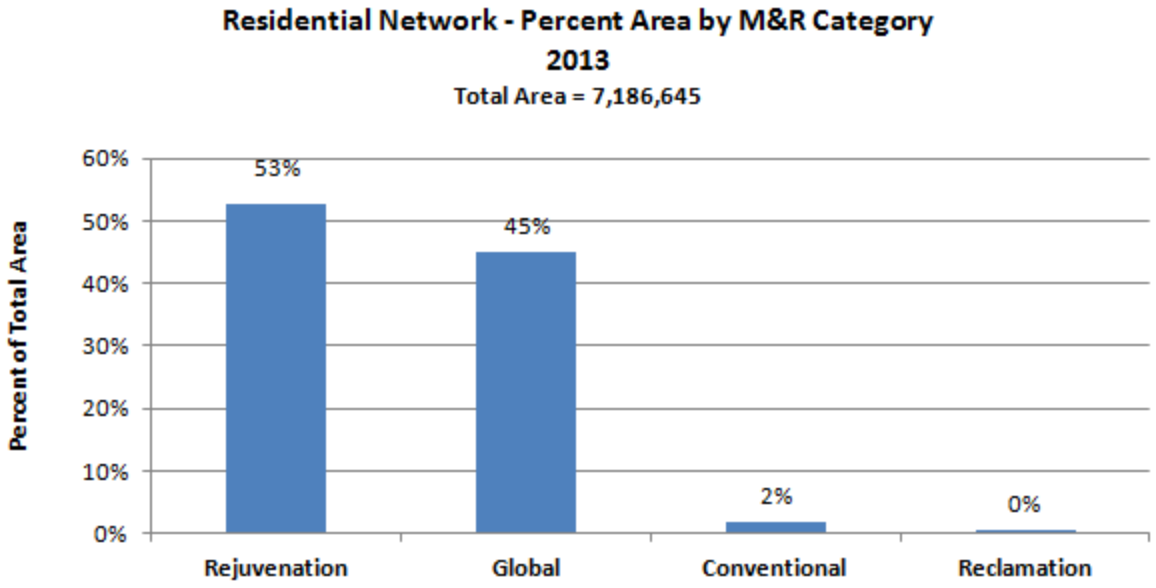


Figure 4-5: Collector Network- Percent Total Area by M&R Categories in 2013

Residential Network for 2013 by M&R Category

M&R Cat.	PCI	Sq. Yd.	Sq. Yd. %	Mile	Unit Cost	Cost
Rejuvenation	86-100	3,796,279	53%	208.54	$0.00	$0
Global	61-85	3,236,836	45%	188.27	$3.16	$10,228,402
Conventional	40-60	123,917	2%	7.14	$14.50	$1,796,797
Reclamation	0-39	29,613	0%	1.45	$27.00	$799,551
		7,186,645		405.4		$12,824,750



4.0 MAINTENANCE & REHABILITATION PLANNING

4.1 KEY ANALYSIS INPUTS

All pavement management systems require user inputs in order to establish real world budgets and pavement maintenance & rehabilitation (M&R) plans. During the boot camp, decisions were made that affect the pavement rehabilitation program in a variety of ways. The key inputs are:

- The M&R Pavement Preservation Categories
- The M&R pavement treatment type
- The PCI ranges assigned to the M&R categories
- Unit cost per square yard for each pavement treatment type
- Expected life of the treatment type
- Agency budget and length of the planning period
- Budget required to achieve a target PCI at the end of the planning period
- Desired backlog at the end of the planning period

4.2 PAVEMENT PRESERVATION

Figure 4-1 represents the APWA/industry standard pavement preservation curve.

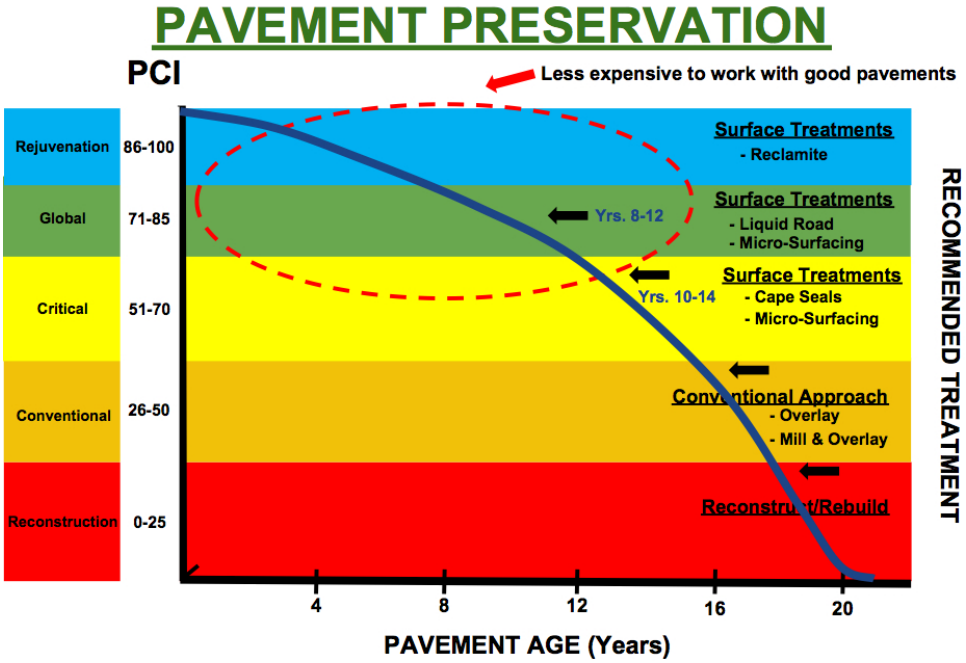


Figure 4-1 Pavement Preservation

Figure 4-2 represents APWA's pavement toolbox. This toolbox looks at possible preservation treatments and how they are cost effective to use as opposed to spending all funding on worst-first maintenance (rehabilitation/reconstruction).

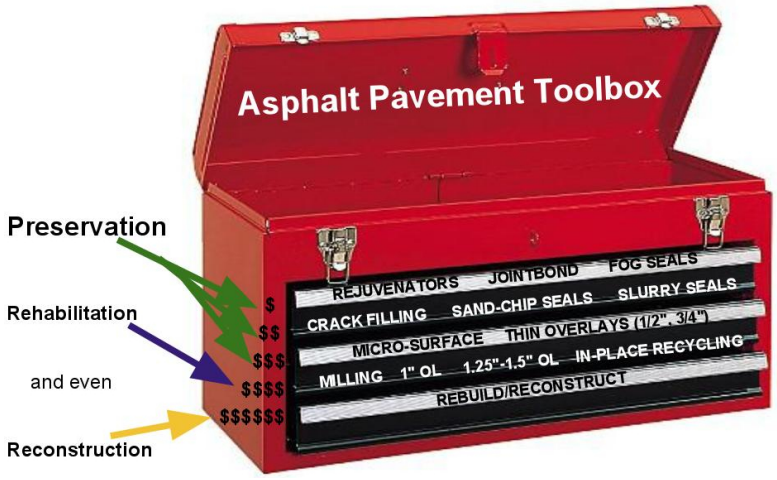


Figure 4-2 Preservation Treatments

This hierarchical strategy ensures that roadways slated for reconstruction remain in the reconstruction pipeline, even if there is a funding shortfall. Available funds are used to preserve those streets that can be treated with slurries and overlays. No real equity is lost when those roads become unacceptable for use, since they were already scheduled for reconstruction.

M&R Categories for the network

Table 4-1 represents the four M&R categories and the associated price per square yard for year 2013 as defined by the Killeen staff. The table also represents what would happen if no treatments were applied for five years (2018) and how the funding needed to repair the system would increase by **2.2** times.

M&R Category, Treatment, Price, and Expected Result (based on current M&R)

M&R Category	M&R Treatment	Price per Square Yard	Expected Result
Rejuvenation (PCI 86 -100)	Do Nothing	$0.00	
Global (PCI 61-85)	Crack Seal/Slurry Seal	$2.65 Slurry Seal, $0.51 Crack Seal	5 year stabilization
Conventional (PCI 40 - 60)	1.5" Mill and Pave	$14.50	10 - 15 Years (Reset PCI to 100)
Reconstruction (PCI 0 -39)	Full Depth Reclamation	$27.00	20 - 25 Years (Reset PCI to 100)

Table 4-1

The values in Table 4-1, M&R Treatment and Costs (price per square yard), will be used in the remainder of the report. Transmap has attached maps and printed reports that use these four M&R categories. The maps and reports are broken out by segment and have funding for each M&R category.

The Killeen staff requested that Transmap conduct a sensitivity analysis using the worst-first approach to maintenance of the system. This analysis focused on the 2013 conventional and global M&R Categories, and was completed using an Excel Spreadsheets. The details are provided below.

Legacy Data

- City does not have legacy MicroPaver data
- Transmap will include all (existing) centerline fields in MicroPaver load
- COG will provide Council districts and ADT Data
- Work history up to 2007 is in the previously provided Pavement_Sections centerline

Total Network for 2013 by M&R Category

M&R Cat	PCI	Sq. Yd.	Sq. Yd. %	Mile	Unit Cost	2013 Cost
Rejuvenation	86-100	4,872,455	52%	250.56	$0.00	$0
Global	61-85	4,284,420	46%	234.45	$3.16	$13,538,767
Conventional	40-60	165,211	2%	8.88	$14.50	$2,395,560
Reconstruction	0-39	30,828	0%	1.52	$27.00	$832,356
Total		**9,352,914**		**495.41**		**$16,766,683**

Table 4-2

Total Network for 2018 by M&R Category (if no treatments were applied.)

M&R Cat	PCI	Sq. Yd.	Sq. Yd. %	Mile	Unit Cost	2013 Cost
Rejuvenation	86-100	944,482	10%	41.68	$0.00	$0
Global	61-85	7,685,831	82%	413.84	$3.16	$25,617,589
Conventional	40-60	648,776	7%	36.37	$14.50	$9,495,243
Reconstruction	0-39	73,826	1%	3.52	$27.00	$1,993,308
Total		**9,352,914**		**495.41**		**$37,106,140**

Table 4-3

5.0 NETWORK BUDGET ANALYSIS

The analysis below has the following set of assumptions:

- The dollar figures were not adjusted for inflation.
- Until Killeen has sufficient years of data to develop their own performance curves, deducts will be assigned based on the performance curve developed from the Texas DOT. Please refer to section 3.1 for details.
- Current budget is $1.75 Million per year
  City estimates it would be around $10 Million to 'Catch Up'.
  CIP funding is $10 Million every five years, $1.75M per year after
- Transmap will provide recommendation maps for $1.75 Million budget as well as a "Fix All" scenario.

The following section contains the budget analysis under current :

5.1 Worst-first approach for Network using $1.75 Million annual budget.
5.2 Capital Improvement Program (CIP) First and Second year for the repair of pavements in the Reconstruction M&R Category.

5.1 Total Network using a $500k Annual Budget

This section shows the impact of an annual $500k budget, worst-first, has on the network level average PCI.

Year	Weighted Average PCI	Change in PCI	Actual Cost	# of sections	Miles (Total Miles=495)
2013	83.57				
2014	81.95	drop 1.62	$510,438	12	0.84
2015	80.29	drop 1.66	$467,655	15	0.95
2016	78.63	drop 1.66	$504,193	15	1.01
2017	77.03	drop 1.60	$497,157	31	1.71
2018	75.42	drop 1.61	$506,672	33	2.07
Total		**drop 8.15**	**$2,486,115**	**106**	**6.58**

Table 5-1: $500k Annual Budget, based on a worst-first selection.

Under this budget scenario, the network level PCI seems to have stabilized at a drop of 1.66 points per year. There is no pavement sections in the reconstruction (backlog) M&R Category. The budget allows one or two centerline miles of pavement for repairs.

5.2 Total Network using a $1.75 Million Annual Budget

This section shows the impact of an annual $1.75 Million budget, preventative maintenance, has on the network level average PCI. The preventative maintenance split was a 50%/50% between the Conventional Approach and Global Maintenance. Also completing the Reconstruction backlog.

Year	Weighted Average PCI	Change in PCI	Actual Cost	# of sections	Miles (Total Miles=495)
2013	83.57				
2014	81.80	drop 1.78	$1,751,390	246	18.61
2015	80.73	drop 1.07	$1,739,230	243	18.41
2016	79.37	drop 1.36	$1,759,323	220	18.92
2017	78.06	drop 1.31	$1,750,920	214	18.27
2018	76.80	drop 1.26	$1,758,300	311	29.81
Total		**drop 6.78**	**$8,759,163**	**1,234**	**104.02**

Table 5-2: $1.75M Annual Budget, based on a worst-first selection split 50/50 between the Conventional Approach and Global Maintenance. After also completing the Reconstruction backlog.

Capital Improvement Program (CIP)

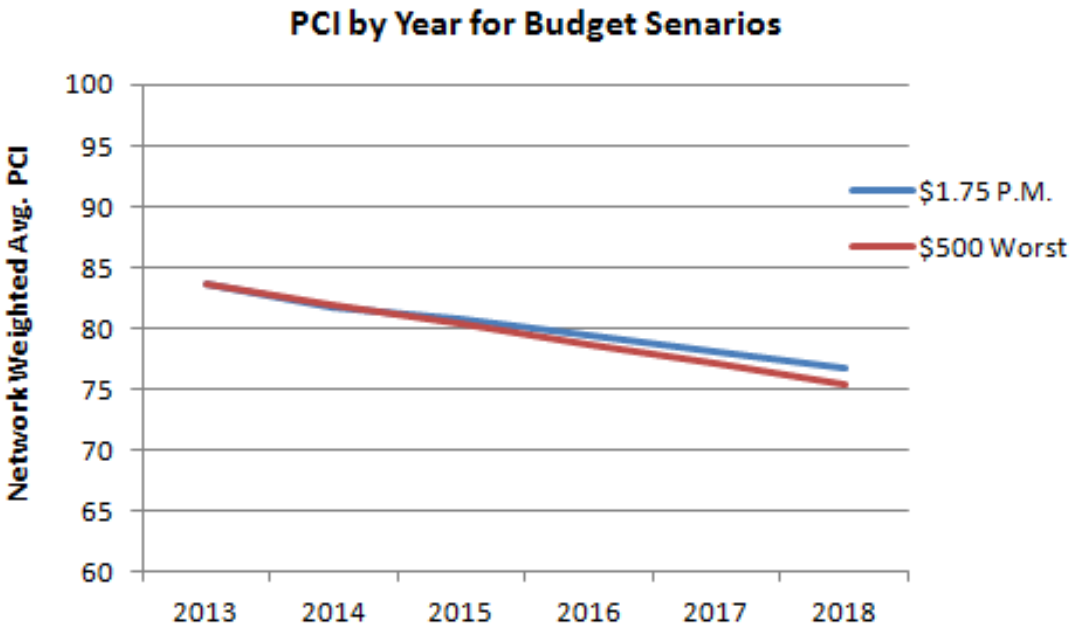
First and Second Year for repair of pavements in the Reconstruction M&R Category

Table 5-3 shows the Capital Improvement Plan for 2014 & 2015

Year	Weighted Average PCI	Actual Cost	# of sections	Miles (Total Miles=495)
2013	83.57			
2014	81.80	$832,365	23	1.52
2015	80.73	$240,897	6	0.5
Total		$1,073,262	29	2.02

Table 5-3: The Capital Improvement Plan spread out over the next two years to repair the sections of pavement within the Reconstruction M&R category.

Below is a graph showing the comparison of the two budgets: $500k worst-first approach and the $1.75M annual budget using the Preventative Maintenance (P.M.) approach.



6.0 SUMMARY

Table 5-1 shows that the $500k annual budget allows the average network PCI to drop 8.15 points in the 5-year period. This is a troublesome trend and action is necessary for its reversal. If sufficient funds are not provided now, there will be an additional cost for maintenance treatments in the future. The PCI of pavements will drop from the Global M&R Category into the Conventional M&R Category. Transmap recommends using the APWA preventative maintenance approach to start reversing this trend.

With only 30,828 square yards of surface area in the M&R Reconstruction Category, the staff is doing a great job maintaining the city streets within the given budget. However, at the current budget level, the PCI will continue to slowly decline. The City staff should consider ways to obtain additional funds to allocate to repairs while attempting to keep the remainder of the network in or above the Global M&R Category. Money spent on timely pavement preservation techniques, such as crack seal/slurry seal or chip seal allows Killeen to keep their higher scoring roadways at a high level of service without a significant increase in backlog.

The $1.75M preventative maintenance budget allows the average network PCI to drop almost 3.78 points in the 5-year period. The biggest advantage in support of this budget is that the maintenance repairs impacts 104 centerline miles of streets. While the $500k budget only allows coverage for 6.6 centerline miles of streets.

Killeen should be able to see dramatic and sustained improvement in the condition of its street network, concurrent with its use of regular pavement condition surveys. The system enables the staff to forecast future needs, conduct research that contributes to improved pavement performance, and maximize pavement investments by objectively prioritizing roadway preservation and improvement projects.

In addition, the Pavement Management System provides a rational basis for communicating with the internal and external customers about stewardship of the City's infrastructure. The staff has the tools to blend reliable data for use in their analysis and to foster two-way communication of the results with decision makers.

It has been Transmap's pleasure to work with the Killeen staff to begin the development of a Pavement Management System. We are certain that the information provided is useful in keeping the network in optimum condition given budget constraints.