Executive Summary

Introduction

The future of our local economy is uncertain, but one thing we know we must manage our infrastructure smarter. State and local agencies are facing challenging times. There are over 600 lane miles of roads with limited or reduced funds for maintenance. During the last 2 years MUED delivered $3.8 million (43 lane miles) in pavement projects. This year we plan to deliver $1.2 million in pavement project for over 14 lane miles of roads. This is due in large part to grants funds and sources other than general funds. Going forward we may not have access to these funds and will need to leverage our dollars to do more with less. A major challenge is how to balance the needs between preservation, system expansion, and system management and continue to serve our objective in providing class A service to our community. Our aim now is to slow the rate of deterioration of our existing road network using pavement preservation and rehabilitation treatments. The development of a new Pavement Management Program is a large step in the right direction. This new tool will assist in determining the most cost effective treatments to apply on a given street segment at a given time.

Purpose of the Study

Municipal Utilities and Engineering Department has developed a citywide 2012 Pavement Management Program (PMP). In developing this program, the physical condition of City street surfaces were evaluated, rated, and the projected life cycle determined. The PMP further identifies a schedule for maintenance and reconstruction of City streets at the appropriate time intervals in order to extend their overall life-expectancy in the most efficient and economical manner. Additionally, the PMP establishes a comprehensive process to prioritize rehabilitation of the City's roadway system and will be used in the decision-making process in order to best utilize the City's available financial resources.

Other advantages of this program include:

1. Improving the quality of the City's streets in a fiscally responsible manner;
2. Implementing a plan that considers both immediate and long-term needs;
3. Promoting transparency by educating public on the decision-making process involving selection and utilization of street improvement funds throughout the City.

Summary of Findings

The City's street network system consists of over 292 street miles or approximately 640 lane miles of Asphalt Concrete paved streets.

Staff utilized eRoads Pavement technology, or simply "eRoads", as an automated pavement evaluation system to create a database of the current inventory of City street conditions, treatment options, and cost estimates for each treatment available. Using this system, it has been confirmed that due to the lack of a comprehensive and systematic maintenance program of the City's road system over a number of years, the City's average Pavement Condition Index (PCI) has dropped to 53 on a scale of 0-100, 100 being a new street and 0 being a street needing full reconstruction. An average PCI of 53 is considered poor according to industry standard and in comparison to surrounding cities.

Various rehabilitation and resurfacing methods are available to maintain a road surface, each with their own benefits and expected service life. To maximize the City's resources, the appropriate treatment must be selected for each road's condition, many of which are described in the PMP report.

New pavement deteriorates slowly at first, then at a continually increasing rate. This deterioration can be significantly slowed by use of systematic preventive maintenance starting in the early stages of a pavement's lifecycle. Examples of different pavement conditions and related PCI values are shown within the report for reference.

Analysis and Recommendations

Recent practices have demonstrated that it is fiscally prudent to maintain roads that are in a relatively good condition. This can be accomplished using low cost treatment methods to prevent them from deteriorating into a more damaged condition. The intent of this report is to provide a comprehensive plan for a strategic street maintenance and rehabilitation program.

Two methodologies for priority ranking have been established, one considers a short-term "value-engineering" that may be applied as funds become available, and the other considers long-term planning. Both methodologies account for the uncertainties of timing and the amount of available funding.

The *VMT Method* is a more focused, or fine-tuned method that relies primarily on the actual usage of each road, expressed in terms of average daily traffic (ADT). The ADT for a road segment is multiplied by the length of that segment (in miles) to produce the vehicle-miles of travel (VMT) per day. Each day there are 814,000 VMT on roads within the City of Redlands. By using the VMT as a guide for choosing roads that will be included in a paving project, the dollars spent will impact the greatest possible number of vehicular trips.

A *Matrix-Method* used for road prioritization involves a variety of criteria including PCI. Although the ranking for the PCI determines its condition, other factors such as street type, bus routes, and the surrounding population density contribute to prioritizing for each road segment. The matrix methodology relies on the available data which is processed using the City's GIS system. The result is a long-term, "big-picture" approach that graphically shows roads that warrant treatments based on function, location, and condition of the road surface.

Section 1
Introduction

Need for Pavement Management

The network of paved roads within the City has been without a comprehensive maintenance/rehabilitation plan since the City's incorporation in 1888. While the City has grown to its current population of 70,000+, increased demand has been placed on the road system as residents drive to work, shop, and have their needs met with the assistance of truck and bus services. Many roads experience traffic counts beyond their intended design, furthering the deterioration of the road surface. With a limited budget for road maintenance, identifying a solution to maintaining the City's road system using treatment methods that will provide the greatest benefit to the community is the objective of this program.

The City generally has three classes of roads: local, minor, and major. Local roads are typically those in residential neighborhoods. Minor roads generally function as collectors that receive traffic from multiple local roads and are usually within mixed-use areas. Examples of collector roads include Olive Avenue, Fern Avenue and Colton Avenue. Major roads experience the highest traffic volumes and function as major transportation corridors. Examples include Redlands Boulevard, Alabama Street and California Street. Figure 1 itemizes these street types by the number of street and lane miles.

Figure 1

CLASS	Street Miles	Lane Miles
Local Street	186	378
Minor Street	58	129
Major Street	48	133
Grand Total	**292**	**640**

Street miles are the lengths of all streets regardless of the number of lanes. Lane miles are defined as the sum of the miles for all lanes in each direction for all streets.

Street Surface Evaluation

During 2007 the City contracted with eRoad to perform a vehicle-mounted survey of all paved roads within City limits. Each segment of road was assigned a PCI value. A verbal description of these values is shown on the table below based on the ASTM *Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys*.

Rated on a scale of 0 to 100, the PCI originated with the U.S. Army Corps of Engineers and was then adopted by the Department of Defense (DOD) and American Public Works Association (APWA). The numerical rating, with 0 being the worst possible condition and 100 being the best possible condition, is accompanied by a written description of the pavement's condition (1). See Figure 2.

Figure 2

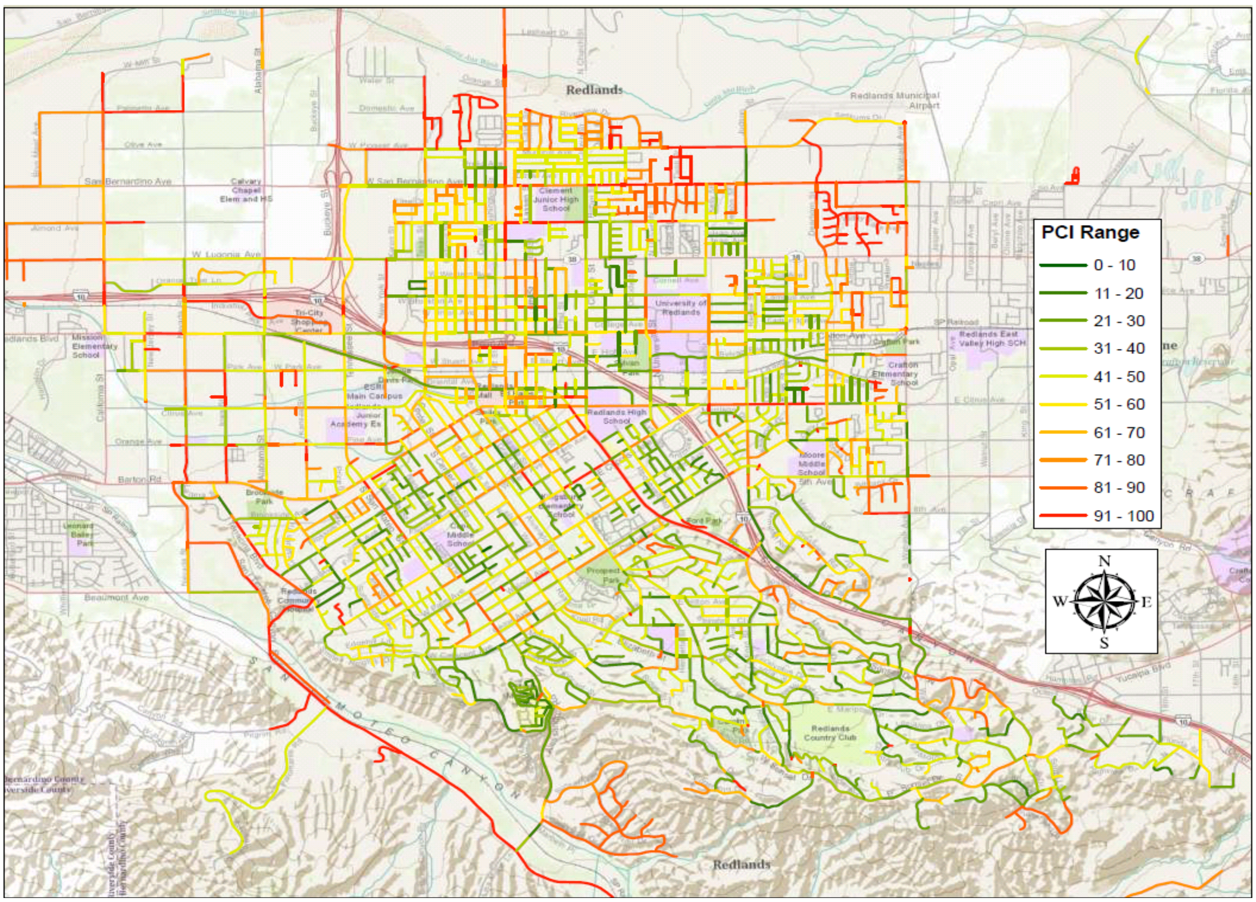
PCI Range	Condition	Description	Recommended Rehabilitation
86 - 100	Good	No significant distress.	Fog seal, Crack Seal, Slurry Seal
71 - 85	Satisfactory	Little distress, may include utility patch work that is in good condition, little weathering.	Crack Seal/ ARAM Slurry
56 - 70	Fair	Slightly to moderately weathered, some distress, some patchwork.	Dig-outs/ ARAM Slurry
41 - 55	Poor	Severely weathered, moderate distress limited to non-load-related cracking.	Edge Grind/ Overlay
26 - 40	Very Poor	Moderate to severe distress including load related cracking (i.e.; large amounts of alligatoring).	Grind/ Overlay
11 - 25	Serious	Severe distress or large amounts of distortion or alligatoring throughout the roadway.	Dig-outs/ Reconstruction
0 - 10	Failed	Pavement has failed; distress is beyond the capabilities of rehabilitation.	Reconstruction

The information from eRoad allows the City to access the PCI of any road for planning purposes as well as for general inquiry from customers. eRoad also color-codes the PCI values onto a map of the City. See PCI Map, next page. Additional information can be obtained for each segment of road including the presence of cracking, rutting, and a recommended treatment as well as a cost estimate.

The condition of a road is impacted by several factors:

- Traffic patterns and loading;
- Structural section (asphalt over aggregate base, asphalt over native soil, or asphalt over crushed rock);
- Characteristics of the underlying soil (high clay content, sandy, gravely);
- Drainage (excessive runoff from lawns, puddling, storm runoff);
- Previous maintenance;
- Quantity of utility trenching and related repairs.

The above items are contributing factors to the overall pavement condition and lifespan of a road. Because PCI varies along a length of road, there are challenges to selecting a uniform treatment for a paving project within a selected area.



<u>PCI Map</u> (Not to Scale)

Designated bicycle and bus routes can be overlain onto the projected paving plan using GIS. This shows the user if coordination needs to be made with Omnitrans or if special temporary traffic controls, such as detours, are necessary for truck traffic for a paving project. Bicycle facilities are also shown to let designers know if new signage and/or striping are applicable.

In the eRoad database, it was determined the City has an average PCI of 53, which qualifies as a "poor" road condition. This rating is lower than the state PCI average of 66, and also lower than the San Bernardino County average PCI of 70 (2). Photographs on pages 15 and 16 provide visual representation of these road conditions.

Pavement Treatment Options

Options for treating and maintaining the paved surface include a combination of pavement rehabilitation and resurfacing in addition to reconstruction. Depending on the goals and available funding, various options are available to specify a scope of work for any given project. For example, some funding sources stipulate "green" technology that uses recycled material for asphalt production such as rubber. Any alternate construction materials and methods must be evaluated for feasibility on future projects. The following is a list of descriptions for conventional construction methods mentioned in this report.

The following 5 pages describe a variety of treatment methods for pavement rehabilitation. The appropriate method that would be selected is based on the condition of the existing pavement.

Fog Seal – Light application of a diluted asphalt emulsion applied directly on the road surface. This treatment seals pavement and slows oxidation.

Benefits:

- Rejuvenates dry and brittle asphalt surfaces
- Seals very small cracks voids at the surface
- Slows weathering and oxidation

Appropriate For:
Good pavements showing only the most minor cracking, weathering, or raveling.

Service Life: 1 - 2 years.

Crack Seal– Bituminous sealant applied to cracks in the paved surface.

Benefits:

- Prevents intrusion of moisture and debris through cracks
- Prevents water damage to pavement structure

Appropriate for: Cracks less than 1” wide and spaced uniformly along the pavement.

Service Life: 3 – 5 years.

Slurry Seal – A mixture of dense-graded fine aggregates and asphalt emulsion applied to the road surface.

Benefits:

- Waterproofs the paved surface and seals small cracks
- Improves ride quality
- Provides skid resistance
- Provides a “sacrificial” wearing course for the roadway.

Appropriate for:
Stable pavements showing minor distress such as some cracking, raveling, and roughness.

Service Life: 3 – 5 years

Microsurfacing – Generally a “high-end” slurry seal primarily used to prevent raveling and oxidation of the road surface.

Benefits:

- Waterproofs the paved surface and seals small cracks
- Improves ride quality
- Provides skid resistance
- Used to level minor rutting of the roadway

Appropriate for:
Stable pavements showing minor distress such as some cracking, raveling, and roughness. Also used for roads showing rutting.

Service Life: 5 – 7 years

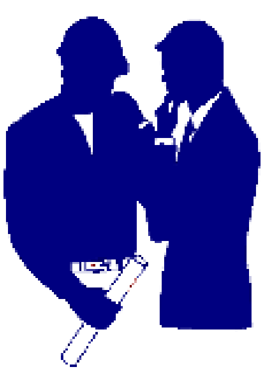
Rubberized Emulsified Aggregate Slurry (REAS) – A “green” slurry seal manufactured with a recycled crumb rubber emulsifier.

Benefits:

- Waterproofs the paved surface and seals small cracks
- Improves ride quality
- Provides skid resistance
- Provides a “sacrificial” wearing course for the roadway.
- More resistance to fading allows pavement markings to remain sharp and bright longer

Appropriate for:
Stable pavements showing minor distress such as some cracking, raveling, and roughness.

Service Life: 5 – 7 years



ARAM – Asphalt Rubberized Aggregate Membrane. Rubberized asphalt emulsion applied to the pavement surface, followed by a layer of aggregates that are rolled, followed by a top layer of rubberized slurry.

Benefits:

- Improves surface friction
- Slows surface raveling, seals small cracks
- Improves ride quality

Appropriate for:
Stable pavements showing minor distress such as cracking, raveling, and roughness. Also effective at sealing more severe cracking than a slurry seal treatment.

Service Life: 5 – 7 years

Grind and overlay – 1" to 2" of roadway are milled to remove the upper portion of the road surface. New asphalt, preferably rubberized hot-mix (ARHM) is then applied at generally the same thickness as the removed portion.

Benefits:

- Removes bumps, cracks and irregularities
- Provides a new course of uniform pavement, not patchwork
- ARHM uses recycled tires and is considered a "green" construction product.

Appropriate for:

Roads with a stable, undamaged base course in which the pavement section is alligatored and/or severely weathered.

Service Life: Up to 20 years (when ARHM is used).

Cold-in-Place Recycling (CIR) – 2” – 4” of the pavement are milled similar to the grind and overlay method. The grindings are blended on-site with an emulsion and rolled back onto the roadway as a new pavement course (typically performed using a caravan of special vehicles that executes these steps in a single pass). This is a “green” construction method that recycles portions of the existing asphalt concrete. Caution must be exercised; the existing pavement section must be capable of withstanding the loading from the caravan vehicles.

Full-Depth Reclamation (FDR) – Consists of removal of the pavement and nearly all of the base sections. Removed asphalt concrete and base material is pulverized and recycled into new base material. The final step is the application of a new course of pavement. This method requires soil testing so an appropriate pavement section may be designed prior to commencement of work.

Applying Pavement Treatment Options

It is recommended the City employ a strategy that prioritizes maintenance activities for streets that are already in a good condition or better. While it may be tempting to follow a “worst-first” plan in which those roads having the lowest PCI rating will receive paving treatments first, regardless of their location or usage, that strategy is generally not cost effective.

Treatments for failed streets will apply large budgets to relatively small sections of road, thereby having a minimal effect on increasing the city-wide PCI average. While failed streets are treated and reconstructed, the at-risk streets deteriorate into a failed condition, resulting in more backlog of failed roads, not less. This will also leave insufficient funds available for less costly treatments to be used at the right place and at the right time. Maintenance and rehabilitation treatments used in this manner will allow more section of road to experience improvement in its pavement condition.

Pavement Lifecycle

The City will consider various rehabilitation methods to maintain its streets. Figures 3 and 4 identify the life cycle of a typical street and the required maintenance based on the condition.

In a typical life cycle of pavement, the condition deteriorates slowly at first, then at a continually increasing rate. In general, a street's condition will deteriorate approximately 40% during the first 75% of its lifespan, assumed to be 25 years for illustration purposes. After 75% of the lifespan has passed, streets will deteriorate an additional 40% over the next 12-17% of the lifespan. (See *Pavement and Cost Lifecycle* curve, Figure 3).

Preventive maintenance treatments performed systematically during the first 75% of the lifespan is key to providing the most cost effective method for extending the life of a paved surface. Re-paving a street once it has deteriorated to a PCI of 25 or less requires costly treatments, such as full reconstruction, which may cost more than twice as much as the sum of the preventative treatments made during the same time period.

Protecting the road subgrade from the negative impacts of water intrusion using crack and slurry seals during the early stages of the pavement lifecycle is one of the most cost effective means of extending the life of the pavement. The degree to which this occurs depends on the type of maintenance and timing of the application. Ideally, some means of maintenance should be performed on a road surface every 5-10 years depending on the condition of the road. Each treatment will improve the PCI and prolong the life of the paved surface if done regularly and will postpone the need for full reconstruction for many years. (See *Pavement Maintenance Cycle* curve on Figure 4).

Photographs

The following pages contain photographs showing examples of various PCI values on Redlands streets.

Barbra Lane (PCI = 14). Severe alligator pattern of cracking on the surface. Very uneven road including patch work.

Brookside Avenue, west of Lakeside Avenue (PCI = 16). Severe alligatoring throughout the roadway. Many patches are uneven within the road surface.

Devon Place (PCI = 16). Severe alligator pattern throughout the road surface. Very uneven road surface.

Michigan Street (PCI = 51). Road surface slightly uneven and weathered. Minor cracking throughout the road surface.

Stillman Avenue (PCI = 52). Road surface is relatively even, although weathered with block cracking and transverse cracks.
Note: Church Street in the background with PCI = 100.

Cajon Street (PCI = 53) near Cypress Avenue. Low to medium severity transverse cracks with low severity of alligatoring.

Palm Avenue near San Jacinto Street (PCI = 66).
Weathered, medium severity transverse cracking with some edge cracks.

Stillman Avenue west of Judson (PCI = 66).
Some weathering, medium severity transverse cracking, low-severity patch work.
Note the different distresses on two roads rated with a PCI of 66.

Barton Road west of Lakeside Avenue (PCI = 70). Moderately weathered road, little or no patchwork. Some minor transverse cracks.

Grandview Avenue (PCI = 90). Note the slight wear/weathering on the road surface.

Church Street south of Colton Avenue (PCI = 100). ARHM is less than a year old. No sign of weathering or distress.

Note the contrast between the ARHM on Church Street (PCI = 100) and Stillman Avenue (PCI = 52).

Section 2
Redlands Pavement Management Program

Methodologies

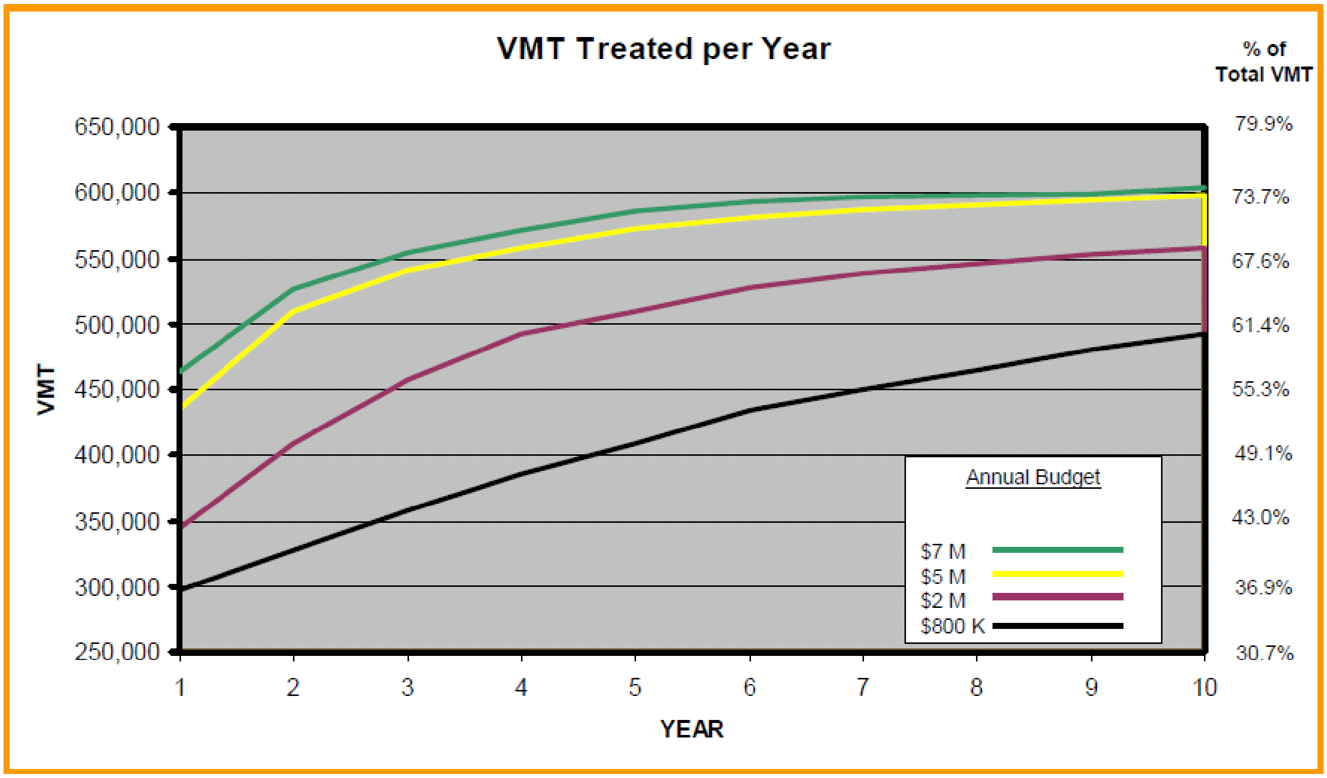
The Pavement Management Program takes a citywide approach to evaluate pavement. This approach requires attaining large amounts of data and resources for analysis to optimize solutions for the entire City, including such things as the coordination of various capital improvement and development projects with paving projects. Using this approach to pavement management has formed two distinct methodologies to prioritize the City's roads for resurfacing. These methodologies are vehicle miles of travel (VMT) and Matrix methods. The availability of funds determine which methodology is most suitable. If funding remains at or near its current level, the VMT is recommended in order to maximize the miles traveled on road surfaces that receive treatment. VMT method prioritizes roads that incur the greatest traffic miles driven, then applies the appropriate repair for that section. Alternatively, the Matrix Method prioritizes improvements based on a set of criteria (listed on pages 19 and 20) to strategize locations for repair. If funding levels exceed current resources available, the Matrix Method is recommended.

VMT Method. The total miles traveled by all vehicles each day in the City is 814,000 VMT/day. Understanding the significance of this number can be illustrated as a single car traveling one and one half round-trips to the moon. The VMT method allows staff to compare the cost of a road treatment with the volume of daily traffic. The total cost of repair or maintenance per average daily traffic (ADT) will yield cost/vehicle trip/day at that location. The lower the cost per vehicle trip, the more cost effective applying treatment to that road will be. See maps for Average Daily Traffic and for Cost/ADT Model Priority following this page.

To create a data model, the ADT for each road segment is multiplied by that segment's length, measured in miles. The result is the VMT. The highest priorities for treatments will be given to those roads with the greatest VMT. Once the data model had been established an annual budget can be entered into the model to chart the progress of road improvements each year for a 10-year time period. This is possible through the eRoad system as each road segment selected for improvement already has a corresponding cost estimate that is based on the recommended treatment for each road segment. Since this method ranks all roads according to their daily VMT, the roads that are selected each year for treatment is a function of the available budget for that year. Once a set of roads are selected according to a given budget, the sum of all VMTs for that group of streets can be used to compare VMT affected per dollars spent. Four different annual budgets were entered into the data model and graphed to illustrate this procedure. See figure 5 on page 18.

Of the 814,000 VMT each day in Redlands, 256,500 of those have already received treatments during the past five years. This is due to high-volume traffic streets, such as Orange Street and Redlands Boulevard, having recently been paved. Using the list of remaining roads, the following ADT and Cost per ADT Priority maps show which streets can be paved based on volume of traffic. For any given budget, the roads with the highest VMT will receive treatment first. Figure 5 shows annual budgets of $800,000, $2 million, $5 million, and $7 million plotted against the total VMT that will benefit from treatment for each year, over the next ten years. Further analysis of these budgets and the impact they have on the city-wide average PCI is contained in appendix A.

Figure 5



The greatest increase in affected VMT per dollars spent appears to be a $2 million annual budget. All curves representing each budget rise sharply at first as funds are applied to a smaller quantity of larger roads with large traffic volumes. Starting around year seven the increase in affected VMT levels out as a larger quantity of smaller roads are treated, yet affecting a much smaller traffic volumes.

Matrix Method. In order to apply budgetary dollars to those roads of highest priority, an assessment was made of the City's needs. Some needs weigh more than others, therefore a weighted criteria was established to define the City's long-term priorities. The set of criteria that contribute to a roads need for treatment are as follows:

eRoad

eRoad is a system that prioritizes streets based on pavement condition.

ADT

The average number of vehicles passing a point, both directions, during a 24-hour period is the average daily traffic (ADT). Roads with higher ADT volumes will receive higher priorities for resurfacing.

Population

Roads that are within areas of higher population density will be given priority over roads that are within areas of low population density. This was determined using a kernel-density function on Census 2010 block centroids.

School or Health Facility

Roads that are within ½ mile radius of a school or health facility will receive an increase in priority. The priority score increases from the ½ mile radius in to the 500 ft buffer of the school or health facility.

Commercial Property

Streets next to commercial and retail centers receive pavement priority based on immediate proximity.

Street Type

Major roads have a greater priority for treatment than Minor roads, which have a greater priority than Local roads.

Pothole
Roads that have a high number of customer-service based calls for pothole and road improvements will be given a higher priority than roads that have not received customer-generated calls. More information about collecting infrastructure problems through the Redlands311 smart phone app or online entry can be found at cityofredlands.org/311

PCI
Greater priority is assigned to roads with a lower PCI.

Bike lane or bike route
Roads that are designated to have a bike lane or are bike route will have a greater priority for resurfacing than roads that will not have either.

Bus Route
Roads that currently serve as Omintrans bus routes will have an increase in priority over roads that do not.

Rail Stop
Roads that are within a ½ -mile radius of a future rail stop will receive a uniform increase in priority.

A map of the Overall Matrix Score follows this page. Appendix B contains a map for each of the above criteria and their geographic "hot spots". Each was assigned a weighted value as a percentage of all the decision-making criteria. The weighted criteria produced a data model that would calculate a priority list of roads to receive treatment. The resulting data model is weighted as follows:

Figure 6

Criteria	Weights (%)
eRoad	20
Average Daily Traffic (ADT)	15
Population	14
School or Health Facility	10
Commercial Property	10
Street type	8
PCI	5
Bike lane or bike route	5
Pothole	5
Bus Route	5
Rail Stop	3
Total	**100%**

Statistical analysis allowed staff to see in geographical terms those road segments where paving treatment was needed most. It is important to remember that this criteria was based on assigned values for each of the criteria listed above. The higher the resulting score for a given road, the higher priority that road has for surface treatment.

According to the Matrix Method priority map, as shown on the next page, those road segments of highest priority are scattered throughout the City. Engineering judgment is required to process this priority, based on weighted criteria, into a scope of work for a specific paving and rehabilitation project.

Utilities

Although outside the analysis process for either the Matrix Method or the VMT Method, future utility work, such as water and sewer facilities, will require adjustment of a road's priority for paving and resurfacing. There are two reasons for this part of the prioritization process. First, paving the full width of a road after completion of utility trenching and patchwork will contribute to an overall increase in the City's average PCI rating. Second, if the patchwork and paving portion of the utility work is concurrent with a separate project to pave the entire road, a cost benefit in the amount of the cost of utility patchwork may be applied towards the total resurfacing cost of that road.

Conclusions

The Pavement Management Program utilizes two systematic approaches along with engineering judgment for determining the street selection priorities and methodologies of repairs. The two approaches are the VMT and Matrix Methods.

VMT Method is an appropriate approach when funds are limited to benefit the greatest amount of vehicle miles traveled throughout the City. With 814,000 vehicle miles traveled daily in the City, targeting the streets that most effect these traveled routes provide the greater benefit to the total miles driven. The downside to this approach is the roads that receive the majority of the attention for repairs will be primarily major streets. This will result in reducing or eliminating residential streets until funds become available or the major streets are all repaired.

The Matrix Method is an appropriate approach when more funding sources are available by using the 11 defined criteria and corresponding weights of each to set the priority for street repair. The benefit to this approach is that streets are paved based on these criteria and not simply vehicle miles traveled. Another benefit to this method is that it does not limit itself to major streets.

The reality is the average condition of City streets are far below what is considered desirable and therefore, it will take many years and resources before all streets receive treatment. The engineer's decision to utilize either of the referenced methodologies or a hybrid of the two for prioritizing resurfacing implementation is directly related to the existing physical condition of each street and availability of resources.