Pavement Management Systems on a Local Level

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PAVEMENT MANAGEMENT SYSTEM ON A LOCAL LEVEL

by

Cristian A. Vasquez

A report submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Civil and Environmental Engineering

Approved:

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UTAH STATE UNIVERSITY
Logan, Utah

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ABSTRACT

Analysis of the Impact of a Pavement Management System for Local Agencies

by

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Utah State University, 2011

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Roads are one of the most valuable infrastructure assets within a community. Proper maintenance of the roadway network can promote the prosperity of a community. In recent times maintenance has become much more difficult with the price of asphalt increasing drastically and city budgets contracting due to the economic downturn. With these conditions, the proper management of an agency’s street network is necessary. The use of pavement management systems provides the help needed in the preservation of the street network. The use of pavement management systems provides significant benefits such as identification of the most cost-effective pavement treatment actions and accurate predictions of pavement deterioration. The research objectives are to examine and explain how local agencies benefit by using an adequate pavement management system and to develop a pavement prediction model appropriate for use in local agencies. This report provides a comparison of three different Pavement Management Systems: TAMS (Transportation Asset Management System), a Pavement Management System (PMS) developed by Utah the LTAP (Local Technical Assistance Program), a PMS developed by the Alabama DOT for use in cities and counties, and Micro PAVER a widely used
commercial PMS. Their unique characteristics and individual strength and weaknesses are discussed so that potential users of PMS can better decide what fits best their agencies' needs. Then TAMS is explained in detail as an example of pavement management system and a case study of its application in Tooele city, Utah. Then an economic analysis of no pavement management, a partial pavement management system, and a full pavement management system is provided. The full Pavement Management System showed a savings of about $32,000,000 over a 40-year period for the city when compared to a no maintenance option.

The results have shown that the use of a Pavement Management System is greatly beneficial for local agencies. This helps to maintain the road network in a good condition without exceeding the given budget as shown in the case study of Tooele city. Furthermore, we see that the cost-saving impact is more dramatic over longer period of times as shown in the economic analysis. Additionally, the comparison of the different Pavement Management Systems revealed that different agencies have different needs and thus the different options of Pavement Management Systems allows them to efficiently choose what works best for them. However, there is still room for improvement in the development of Pavement Management Systems.
DEDICATION

This report is dedicated to my father Absalón, who is the greatest example of hard work and intelligence I have ever had. To my mother Isabel, who gave me lots of love, support and motivation throughout my whole life. To my siblings Issaak, Ysabel and Alberto. Finally to all my friends and extended family, who have supported me with their friendship, care and example to achieve everything I have achieved throughout my life.

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CHAPTER 1
INTRODUCTION

1.1 Problem Overview

A road network is one of the most valuable infrastructure assets within a community. Proper maintenance of these transportation assets can promote and enhance the safety and prosperity of a community. However, maintenance of these assets for local agencies (cities and counties) has recently become much more difficult for several different reasons.

Recently road networks' maintenance in a local level has been challenged by the drastic increase in asphalt prices as well as city budgets contracting due to the economic downturn. Moreover, road networks’ maintenance price already accounted for a big portion of cities’ public works budget. Therefore, the proper management of an agency's street network is necessary. If road networks are allowed to deteriorate to a poor category, maintenance will become even harder and costlier since reconstruction treatments are much more costly and less cost-effective than preventative treatments. Whenever road networks are allowed to deteriorate to a poor category, the cost of repairing and bringing the network’s life and serviceability back to an acceptable level dramatically increases and goes well beyond the city’s original roads budget. Despite these challenges there is still not a general procedure for pavement management systems in a local level.

This report is based on an extensive literature review and case studies of pavement Management Systems: First, an extensive literature review was provided. This
included: General description of Pavement Management Systems, problems encountered by agencies, pavement performance models, benefits of using PMS. The literature review also includes a complete description of the algorithms used within the Utah LTAP (Local Technical Assistance Program) pavement management software, a deep comparison of three different, representative software used at local levels (including Utah LTAP’s software) and some improvements performed to the Utah LTAP pavement management software released while this report was being written. Second, a Pavement Management System is used in Tooele City - Utah and its results are analyzed and presented. Finally an economic analysis is provided to show the long term economic benefits that the use of PMS has on the economic side.

1.2 Research Objectives

The main goal of this research is to improve the current asset management practice in Pavement Management Systems. This can be explained better in these three major objectives. First, is to explain the algorithms and functionalities of the Utah LTAP pavement management system, compare it with other local level PMSs, and describe the process followed in the release of its latest version which improves some features of the software. Second, is to present a Pavement Management system methodology and its use between the years 2000 and 2009 in Tooele City, Utah.

1.3 Research Approach

The literature review consists of an analysis of various technical papers as well as several other information sources in order to provide a summary of the state of the art in
pavement management systems procedures. Topics investigated include but are not limited to: PMSs higher-level methodologies used at state and federal levels, applications of PMSs designed for local agencies, pavement life modeling, commercial PMSs and pavement treatments efficiency. The literature review serves the purpose of understanding the current state-of-practice technologies, as well as their current strengths and weaknesses in pavement management systems.

Next a pavement management system is used in Tooele city, Utah and its procedure and results are analyzed. This section of the research examines the efficacy of the Pavement management efficacy of the Pavement management system performed to Tooele city in the years 2000, 2004 and 2009. Employees at the Utah LTAP Center performed a complete road condition survey at each year using the Strategic Highway Research Program (SHRP) Distress Manual as a guide to conduct the pavement distress survey. At each year recommendations were given to the city officials as how to treat their road network in order to maintain the serviceability and life of their road network. The costs and results of these recommendations were analyzed for the 2000-2004 and 2005-2009 periods. Furthermore, an economic analysis of three different preservation strategies was conducted supporting evaluation and comparison for Tooele's road network. This analysis is intended to better show the possible economic benefits of the use of pavement management system over time.

1.4 Research Contributions

Even though extensive research has been done in the area of Pavement Management Systems, there is still a lack of a general procedure to manage pavement
networks at the local level. The main goals of this research are to provide an alternative algorithm to the existing pavement management systems, present a case study where this pavement management system has been successfully applied, and to evaluate and improve the pavement deterioration estimation provided by the Utah LTAP pavement management system.

1.5 Project Report layout

This current chapter (Chapter one) consists on the introduction. Chapter two contains an extensive literature review of research on existing PMS methods and a profound explanation of the algorithms involved in the Utah LTAP pavement management system. Chapter Three is a paper on a practice-proven pavement management system and its case study on Tooele City, Utah. Finally, Chapter Four concludes the report with findings, conclusions and recommendations for further research.
CHAPTER 2
LITERATURE REVIEW

There has been extensive research on pavement management systems in the last 25 years. A large number of pavement management systems have been developed and implemented in the last two decades ranging from very simple to very sophisticated systems (AASHTO 2001). Agencies have tried other ways to manage their road networks such as just using spreadsheets or on a basis of how many complaints are received on each road. These methods, which lack a minimum degree of sophistication, have not been met with much success.

In recent years asset management has become important because the public wants to see the federal, state, and local governments operate more like private businesses. They want to see better management of the resources that were paid for with their tax dollars (Tavaloki et. al. 1992). The use of a PMS program can help local agencies satisfy this demand and begin to operate more like a business by enabling them establish goals, prioritize projects, and make a complete inventory of the network within the PMS program. The goal of a pavement management system is to optimize the value of the maintenance funds and to provide the highest possible pavement quality with the allocated resources (Wells 1984). When these goals are met, the funds that are left over can be used to expand the existing system and maximizing the use of tax dollars. By maximizing the use of tax dollars the general public will trust into the road networks and will provide for economic growth.
2.1 General Description

A pavement management system refers to an integrated set of systematic procedures designed to assist engineers and managers in making consistent and cost-effective decisions related to the design, maintenance, and restoration of pavements (Wells 1984). Pavement performance models are used to predict future pavement condition which helps determine the treatments required for the pavement (De Melo e Silva et. al. 2000). A well designed pavement management system can be used in more sophisticated engineering applications such as determining which pavements perform in a superior or inferior manner (Baker et. al. 2004). Prediction models are used for condition forecasting, budget planning, inspection scheduling, and work planning (De Melo e Silva et. al. 2000). The major objectives of a network-level pavement management system are to develop short and long-term budget requirements and to produce a list of potential projects based on a limited budget (Butt et. al. 1994).

A PMS is an asset management system that assists decision makers in finding optimum strategies for providing and maintaining pavements in a serviceable condition over a given period of time (Zavitski et. al. 2006). A PMS is an organizational and computational program used to catalog pavements, recognize their current condition, realize their deterioration rates, and review various methods and degrees of maintenance and repair to assess the costs of those repairs now and in the near future (Anderson 2005).

Typically a PMS is considered the downgraded, simplified version of an asset management system (AMS). The Federal Highway Administration defines an AMS as “a systematic process of maintaining, upgrading, and operating physical assets cost-
effectively” (Tavakoli et. al. 1992). While they have similar purposes, an AMS is much more intricate, resulting in operational and maintenance costs that are significantly higher long-term. Budgets for the department of transportation at state level are higher, affording use of the more sophisticated system. When it comes to local agencies, they lack the budget to implement the more sophisticated system.

The goal of a pavement management system is to optimize the value of maintenance funds and to provide the highest possible pavement quality with the allocated resources (Anderson 2005). A PMS is an asset management system that assists decision makers in finding optimum strategies for providing and maintaining pavements in a serviceable condition over a given period of time (U.S. Department of Transportation 1999). A PMS is an organizational and computational program used to catalog pavements, recognize their current condition, realize their deterioration rates, and review various methods and degrees of maintenance and repair to assess the costs of those repairs now and in the near future (Anderson 2005). A pavement management system refers to an integrated set of systematic procedures designed to assist engineers and managers in making consistent and cost-effective decisions related to the design, maintenance, and restoration of pavements (Tavakoli 1992).

2.2 Problems encountered by agencies

Agencies are responsible for managing road networks. The inventory and management of these road networks is of special concern to these agencies due to the constant volatility in asphalt prices and the contraction of the already limited available funding. The rise in material cost combined with the lack of funding causes differed
maintenance and can increase the risk of future failure in the local road network. If a county or city engineer can successfully implement a pavement management system, the risk of failure will be drastically reduced.

2.3 Pavement performance models

Pavement performance models are used to predict future pavement condition which helps determine the treatments required for the pavement (de Melo e Silva et. al. 2000). A well-designed pavement management system can be used in more sophisticated engineering applications such as determining which pavements perform in a superior or inferior manner (Baker et. al. 2004). Prediction models are used for condition forecasting, budget planning, inspection scheduling, and work planning (Melo e Silva et. al. 2000). The major objectives of a network-level pavement management system are to develop short and long-term budget requirements and to produce a prioritized list of potential projects based on a limited budget (Butt et. al. 1994).

Kulkarni states that the difficulty in accurately predicting behavior of pavement deterioration and the availability of periodic pavement condition data require a dynamic decision model, rather than a static decision model, to decide selection of cost-effective preservation actions and forecast the future performance of a highway network (Kulkarni 1984). Different sophisticated optimization methods have been proposed by researchers including linear programming, dynamic programming, and integer programming. However, these methods are not appropriate for local agencies because sophisticated methods require more staff, money and expertise to operate than local agencies can usually afford.
2.4 Benefits of using PMS

Managers of low-volume roads face numerous challenges including, but not limited to, budgeting and routine and capital maintenance decision making in resource constrained environments (Ebeling 1989). As such, pavement management systems have been studied and successfully applied at county and city levels where significant cost savings can be achieved through improved maintenance practices (Wells 1984). Underpinning these practices and tools, is an emergence of professional education curriculum about pavement management systems on local levels such as National Highway Institute course 13426, “Road Surface Management for Local Governments” (FHWA 1989). Examples of successful adoption exist such as in Michigan where local agencies are dependent on the pavement management system to assist in managing their pavement network (de Melo e Silva 2000) and have begun to embrace the concepts of asset management at the agency level because it makes business sense (McNinch 2009).

By adopting the phrase ‘good roads cost less’, over time, agencies could save millions of dollars to go towards future expansion of the network (Zavitski et. al. 2006). For example, Utah Department of Transportation (UDOT) performed a study that allowed the entire state highway network to hypothetically deteriorate to poor conditions. They concluded that “a poor highway network impacts the economy and the citizens of Utah through increased accident cost, user costs, agency costs, and delay cost as larger rehabilitation treatments are needed to restore the highway network to a good condition” (Zavitski et. al. 2006). Without using an effective preventive and routine maintenance program, the average city or county may see the cost of maintaining their transportation
system increase to four or five times what it would cost if the proper maintenance were done now (Tavakoli 1992).

Even with a simple model, local agencies receive a lot of benefits from using a management system. Since everything that is input to the software is stored into a database, the database allows the use of queries. Queries allow for very detailed specific searches to be made, such as, getting all the roads that have a remaining service life (RSL) of less than 10 years but greater than 5 years. PMS programs help utilize the network and assist engineers in finding the optimal use of funding and treatments. A PMS program can also help in the communication between the city and/or county to the public by being able to: answer pavement questions for elected officials, better coordination between utility agencies, and improves the credibility when dealing with city officials and the public (U.S. Department of Transportation 2001). The benefits for an agency are endless and these were just a few of them.

Pavement management systems have proven to be extremely beneficial when applied statewide; the implementation of a PMS has changed the pavement management decision process in Arizona from a subjective method to a measurable quantitative system (Golabi et. al. 1982). The Louisiana Department of Transportation and Development statewide pavement distress data collection system has greatly evolved from windshield surveys in the early 1970s to videotaping in 1992 to the Automatic Road Analyzer system in 1995. Currently the pavement network is surveyed once every two years using these methods (Khattak 2008).
2.5 Comparison of different PMS

This section compares three different PMSs: TAMS (Transportation Asset Management System) developed by the Utah LTAP (Local Technical Assistance Program) in order to serve local agencies, a PMS developed by the Alabama Department of Transportation (ALDOT) in order to serve counties and cities in Alabama and MicroPAVER, a commercial PMS widely used by agencies throughout the country. Although these PMSs share some characteristics, there are differences that can distinguish the complexity and quality of the output. This comparison aims to show a few of these differences for agencies that are looking to start using a program or find a different program for the future. By showing these differences the agency can be able to find a pavement management system that meets the needs of their road network.

2.5.1 TAMS

Transportation Assets Management System or TAMS is a Pavement Management System developed by the Utah Local Technical Assistance Program (Utah LTAP) developed to assist local agencies in Utah and surrounding states to implement and use such a tool to maintain, preserve, and enhance their road and street facilities and more effectively manage the allocation of funding as it pertains to the existing street network.

TAMS is a user-friendly software focusing on providing a service that is appropriate for local agencies which usually lack the staff and money to support complex PMS such as the ones used at the state and federal levels.

TAMS uses Geographical Information Systems (GIS) built within the software. This is achieved through the use of agencies’ shapefiles which are connected with the
TAMS’s corresponding database. The use of GIS allows the user to “point and click” on a map to select individual road segments for inventory, condition rating, analysis, and treatment tracking purposes. The use of GIS within the software also allows the PMS user to print maps showing the optimal condition and/or the optimal treatments corresponding to each street network segment. Figure 2.1 shows a map that has been generated with the use of GIS shapefiles.

Figure 2.1 Map using GIS shapefiles.
Data collection is a very time consuming and crucial part of a PMS. Employees from the Utah LTAP Center use the Strategic Highway Research Program (SHRP) Distress Manual as a guide to conduct the pavement distress survey. Inventory details include street name, starting and ending addresses of the segment, functional classification, segment width and length, estimated remaining service life, surface area of the pavement in square yards, and the percent of network area represented by each segment. This inventory excludes pavement structure details regarding date of initial construction, layer thickness, and pavement design criteria of each street. This information can be obtained from historical records, maintenance personnel, or sampling and testing of the pavement structure.

There are two common ways to collect present condition of the road. The first is by calculating the international roughness index (IRI). Then this IRI value is calculated to a pavement serviceability index (PSI) value through the use of an equation. The second most common way to find the present condition of a road is by using pavement condition index (PCI) based on visual inspection rating (VSR). A VSR, also known as a windshield survey, is a rating that is based purely on how the surface of the pavement looks. The most common way to perform the VSR is to drive a vehicle at 20 mph and evaluate how the road looks from the cab of the truck.

The principal focus of the condition survey performed by TAMS was to identify and determine the severity level and extent of each distress type. Each asphalt street segment was closely surveyed with respect to potholes/utility cuts, rutting, transverse cracking, longitudinal cracking, block cracking, edge cracking, and fatigue (alligator) cracking. This is achieved through a visual inspection rating performed while driving a
vehicle at a low speed (VSR). The severity level and extent of each distress type were evaluated in accord with the condition survey evaluation sheet shown in Figure 2; Figure 2 also shows the inventory information form used when surveying the street. The form on the left gives examples of each type of fault and the inventory form is what the user uses to input the data into the program.

Figure 2.2 Left: condition survey evaluation form; right: software inventory form

TAMS assigns a remaining service life (RSL) value ranging from 0 to 20 years to each road segment inventoried. Then TAMS calculates that each road segment deteriorates at a rate of 1 year of RSL per calendar year if no treatment is applied. This is a very simplistic method of predicting individual road segments RSL yet it has worked
well with the agencies that have used TAMS over the last decade. This pavement prediction model also helps to estimate when the whole road network will deteriorate in average to a certain level or when a certain portion of the road network will reach complete failure, characteristics that are very important and often used by city officials.

The database is extremely important for the proper use of TAMS. It stores all the data collected with the software. Also, it allows the use of queries that allow for a better search of detailed and specific information within all the data collected. Furthermore, it also contains different data pertaining to each specific agency which can be easily customized to meet the agencies’ needs. For instance the database contains the information such as: treatment options, treatment options’ associated costs, RSL improvement related to each treatment option which often vary in different agencies.

TAMS is a very affordable software for local agencies. Its cost is already subsidized by the Utah DOT. Its cost for local agencies in Utah is $500 and does not require any additional yearly cost. For out-of Utah-agencies its cost is $1000. This cost acquires the software and technical assistance from the Utah LTAP center located at Utah State University.

Thus use of TAMS is highly recommended for local agencies that need a simple yet effective PMS. Also agencies should realize that the cost of TAMS is already subsidized by the Utah DOT and thus TAMS is very affordable when compared with commercial PMSs.
2.5.2 ALDOT Model

The ALDOT model was developed by the University of Alabama in Huntsville and its use is intended for county and city engineers. It was developed by using Microsoft Visual Basic and C++. It was designed to make “obtaining road information quick, easy, and inexpensive, which is what county engineers wanted” (Anderson and Wilson 2005). This software is used for the networks within counties and cities.

This software does not use GIS to divide the road network into sections, but rather using definite geographical locations, such as bridges or intersections (Anderson and Wilson 2005). The reasoning behind using definite geographical locations is to make sure that contractors and workers know exactly where they are supposed to do work on the road. The way that the road network is divided up is done by the county engineer. The county engineer uses a county map and makes segments that are based on intersections (Anderson and Wilson 2005). Although the developers mention that GIS data would be a great improvement, the GIS data would already have the sectioning of the city or county be done.

The data collection in the ALDOT model focuses on three things: pavement condition index (PCI), average daily traffic (ADT), and the amount of tractor-trailer traffic. The one setback to not using GIS data is that when data is collected, the data collectors using this system need to get the relevant information that includes the length, starting and ending point (geographical), and the date collected. The PCI information is collected using a visual inspection rating or VSR at 20 mph and a picture of the road segment was taken. It was given a rating from one to ten, where the values of nine and ten are excellent condition. The ADT and amount of tractor-trailer information are then
collected by taking traffic counts or obtained from city or county records. Figure 2.3 shows the data collection process for the ALDOT PMS program.

The inventory or input screen is very basic and simple which allows the county engineer to input data quickly and easily. It includes the following: starting/ending point, the length of the section, type of road (asphalt or concrete), classification (arterial, minor/major collector, rural, etc.), district (user-defined), VSR, ADT, percentage of trucks, date that the data was collected and a comment box. It also displays a picture of the road segment. This screen is used to collect the data for PCI by doing a VSR survey.
Figure 2.4 shows this screen that is used to input the data. Once the inventory data is collected and input, there is a maintenance screen that allows the user to input comments about what has or has not been done on the section of roadway. With both the input and maintenance screens the amount of data will help improve the network with accurate and current data.

Figure 2.4 Input screen (left) and the maintenance entry screen (right)
The database that is used in this software allows the use of queries, and has a route reports screen that is specifically for them. It allows the user to only look at certain sections or sections that have similar attributes. The database is the heart of the PMS and is necessary for all the information to be stored in an orderly fashion. Without the use of a database, queries would not be able to be done making searching for similar roads and types of roads harder to obtain.

Figure 2.5, below, shows the route reports which use the queries to give the user information on roads that fit the equation made by the user. The software also has a road history and road inquiry screens and once the data is collected the database automatically updates these screens with accurate and up to date information on a given section. These two screens are similar to the input screen; the few differences are that it shows what type of maintenance has been done and projections of PCI and ADT for the next year. For this PMS model the database allows the engineer to store all the networks information in one convenient and organized location.
The ALDOT model uses linear regression statistical analysis to develop their pavement deterioration model. Deterioration models are used to determine how fast and when pavement will deteriorate to an unserviceable condition. When using a linear
regression model three assumptions must be made. First, the statistical errors are assumed to be normally distributed. The second is the variance of the error is constant. The last assumption is the errors are not dependant (Anderson and Wilson 2005). In this particular model, the variable that is being solved for is the VSR and many different factors were tested before the final equation was satisfied such as average daily traffic (ADT), percent trucks, years ago resurfaced, average daily cars, average daily trucks, yearly passenger cars, etc. Many different combinations of the variables were used to find the best possible solution and the final equation turned out to be \( VSR = 11.2 - 0.09211 \times ADT - 1.76 \times YAR - 0.0711 \% \text{ Trucks} \), where ADT is the average daily traffic, YAR is years ago resurfaced, and \% Trucks is the percent of trucks (Anderson and Wilson 2005).

For agencies that have limited time and money this software would be a great installment for the agency. Its basic and easy software interface allows a new user to be able to spend minimal time to get familiar and to get started. This program took the taxpayers into account while developing this model. It aims to spend the taxpayers’ money as wisely as possible, this should take into account that the software’s cost to the agency. If it is inexpensive for agencies to get started it would help maximize the taxpayer’s money.

2.5.3 Micro PAVER:

The program Micro PAVER or PAVER has been in use since the early 1970’s and has a lot of major U.S. government and private agencies working on the research and development of the current program. The PAVER program was first researched and developed by the United States Army Corps of Engineers. PAVER is used by over 600
agencies that include counties, cities, airports and private agencies (APWA). It is a more commercialized and technical program that requires a lot more computer skills and knowledge.

PAVER has GIS tools integrated into the software directly (PAVER 2003). These tools allow the user to either choose to use a map defined by the agency or to use GIS maps. If the GIS maps are used by the agency, the program works directly ESRI shapefiles (PAVER 2003) and already has the network divided into sections that are defined by the GIS map. When a user wants to use GIS maps, the maps are obtained using the program Map Objects Lite and then importing them into PAVER.

The figure below shows GIS maps in the PAVER system.
Figure 2.6 How to import GIS data (right), and GIS map (left)

The data collection is similar to all of the other programs’ discussed earlier. This program uses a visual inspection rating to get the current condition of the pavement. The developers recommend that when collecting data to use the data collection forms and input the data into the program later. These paper forms display all the pavement stresses and the location data. Although after lot of data collection there will be a big amount of paperwork to input into the system, but it could reduce the risk of inputting data into the system wrong or not at all. This process would take a little longer and could cost more in labor costs to collect and input the data but having the forms would be a good reference to look back on if any confusion would arise.
Being a commercial program, the inventory screen has more features and is more complex to operate. The screen allows the user to select to input or see data at a network, branch, or section level. The network shows data for a broader level and gets more detailed as you go down to the branch level to the most detailed at the section level. The figure below shows data at the section level, it has two different tabs the first tab provides the general data about the section such as the length, width, and the start and end point. Figure 2.7 also shows a sample condition survey form that is used to obtain the current PCI of a given section. The second tab is the condition of the pavement and the family that it is in. This program also lets the user see the current values or the historical values.

**Figure 2.7** Inventory screen (left) and road survey form (right)
The one database tool that the PAVER program has that the other programs don’t have is the Engineered Management System or EMS. EMS is query tool that is used throughout the program in reports and data modeling (PAVER 2003). This tool allows the user to specify the sorting order of sections when working with reports for example. The EMS has a screen called the EMS Report Viewer screen, this screen lets the user define what the user wants to see in forms of reports, spreadsheets, or sections of roads (PAVER 2003). Another useful tool within the databases is the combine/subset. This allows the user to combine databases into one database or to make several databases out of one database.

Prediction modeling in PAVER is called family modeling. The family modeling process is to identify and group pavements of similar construction that are similar traffic patterns, weather, and other factors (PAVER 2003). These factors as well as historical data are used to predict the future performance of pavement. Prediction modeling uses the EMS tool to help predict the pavement performance.

Getting the PAVER program is really easy for an agency to get and can be ordered online, however the program is not free. For first time users the cost is $995 for the first year and $950 dollars every year (TAC 2010). This cost gets the software and technical assistance from the Technical Assistance Center at the University of Illinois at Urbana-Champaign. This can also be purchased from the American Public Works Association (APWA 2010) for similar costs.
2.6 TAMS Update

Utah LTAP constantly received feedback about the TAMS 2.7 version widely used throughout cities and counties in the state of Utah. People providing feedback included local agencies’ engineers and technicians as well as Utah LTAP technicians’ improvement suggestions. Some of the most important suggestions were:

- To facilitate the editing and customization of TAMS databases
- TAMS capability to create maps with segments colored based on attribute type
- Merge databases within TAMS
- Enable the use of queries within TAMS
- Enable TAMS to provide more than 1 optimal solution suggestion in its output
- More sophisticated RSL modeling method

2.6.1 Recommendations implementation into TAMS 3.1

A new version of TAMS has recently (2010) been released by Utah LTAP. This version of TAMS aims to address the common suggestions given to the Utah LTAP in recent years. Some of the improvements made now allow users to: better customize TAMS database, create colored maps based on attribute type within TAMS (no need to use another software), use queries within TAMS (no need to independently open database in order to do that), merge the inventory form with the condition rating sheet (Figure 2.8), improvement of appearance and layout of different forms used within TAMS

Having maps with segments colored based on attribute type is very helpful to agencies’ officials. For instance this allows users to visually examine the data on a map, which helps with the perception and understanding of the data. This is also used by the
users of the PMS in order to visually explain data to non-technical staff or officials about the performance of a street network and concerns about it. The latest version of the PMS described includes this capability whereas the previous version would require the use of another software, (i.e. Arc Map) which is not free, in order to obtain maps with segments colored.

Figure 2.8 shows one of the major improvements in the newly released TAMS 3.1 where now the technician entering distress information can access the extent vs. severity ratings while rating the road.

Figure 2.8 TAMS 3.1 pavement inventory and condition rating sheet form
Figure 2.9 Pavement performance chart over time

Picture 2.10 TAMS 3.1 picture view of digital photos
Figure 2.9 shows the improved pavement performance chart belonging to a specific road segment which shows the ratings given throughout the years and can also show treatments applied to the segment. Figure 2.10 shows the improved display of digital pictures pertaining a specific segment. Figure 2.11 shows the improved work order form of TAMS 3.1. This form has more options and easier user interface than the one in the previous TAMS version.

![Figure 2.11 TAMS 3.1 Work Order form](image)
2.7 Conclusion

The literature review presented examined a wide variety of topics related to pavement management systems which were necessary in order to fully understand the research performed concerning pavement management systems. These topics included: Introduction, general description, problems encountered by agencies, pavement performance models, benefits of using PMS, comparison of different PMSs and TAMS improvements in the newly released 3.1 version.

Additionally, this chapter provided a summary of three pavement management systems, TAMS, the ALDOT model, and PAVER. Even though these software have been developed differently and each has some unique features, they will ultimately serve the same purpose and help an agency keep accurate records and provide data to keep the road network in the best possible condition under budget constraints. TAMS and ALDOT’s model are very simplistic models and easy to use with focus on local agencies. This simplicity makes the program user-friendly, especially for small agencies lacking budget and stuff, and does not take a lot of time to get familiar or even proficient with it. Because it doesn’t take a lot of time the agency can optimize the use of the program. While TAMS and ALDOT are simple, PAVER is more complex. The complex algorithms of PAVER allow the user to get more in-depth, detail specific charts, but more computer knowledge and staff is needed to generate these kinds of reports and analysis. Furthermore, PAVER can (and currently is) be implemented by a wider variety of agencies.
Table 2.1 Overall features of the programs discussed

<table>
<thead>
<tr>
<th>FEATURES</th>
<th>TAMS</th>
<th>ALDOT Model</th>
<th>Micro PAVER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allows the use of GIS Data</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Way data is collected and input into the system</td>
<td>VSR, directly</td>
<td>VSR, directly</td>
<td>VSR, paper forms</td>
</tr>
<tr>
<td>Type of Inventory/Input screen</td>
<td>Basic</td>
<td>Basic</td>
<td>Somewhat complex</td>
</tr>
<tr>
<td>Does it use a database?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Does it allow the use of queries?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Uses a regression model to predict future pavements</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Relative cost to implement the software</td>
<td>Low</td>
<td>Low</td>
<td>Moderate to high</td>
</tr>
<tr>
<td>Overall Complexity</td>
<td>Simple</td>
<td>Simple</td>
<td>Complex</td>
</tr>
</tbody>
</table>

It is up to the agency to decide what management system will work the best for them. Each program that was discussed will optimize the road network and the agency must decide if they want to use a simple or complex program. Table 2.1 above is a brief summary of the common features that were covered in the section. An agency needs to consider all of these items before choosing what system is right for them. Each element requires different levels of computer skills and time needed to get the software to a state where it can be fully utilized. Furthermore, different pavement prediction algorithms may be specific to certain geographic characteristics (i.e. Alabama vs. Utah).

Additionally, the improvements performed to TAMS (3.1 version) show the importance of feedback from local agencies and staff. Many of the concerns/suggestions presented to the Utah LTAP regarding TAMS were taken care of by the release of the latest version. In order to improve PMS a good communication and constant feedback should be held between local agencies and the PMS provider.

The importance of a pavement management system within a local agency is enormous if the agency wants to keep the network well maintained and within the budget.
constraints. An agency needs to implement some sort of pavement management system to maximize productivity in the road network and provide its citizens and users with the best possible service available.

All this literature review shows that even though there has been extensive research regarding PMS in the last decades, there is still a need to bring this knowledge together specially at the local level. Also, because of the difference in needs even between local agencies, flexibility would allow for wider feasible use of PMS. For example, as PMSs accommodate different level of complexity in the inventory process and different pavement prediction models, the program can be successfully used in different-sized agencies as well as cities in different geographical regions.
Pavement management systems (PMS) are of great importance for local governments for several reasons. The first reason is that they provide a means to objectively deal with volatility in pavement treatment and repair costs and variation in annual tax-based revenues as exemplified in the current economic downturn. Second is that sophisticated modeling methods employed at the state and federal levels are inappropriate for local agencies because local agencies lack the staff and money to manage them. Third is that the use of pavement management systems supports better allocation of the local agencies’ money by giving them a means to choose cost-effective ways of treating the pavement network system, and reduce work zone visual and operational impacts.

Recently, the focus of state highway agencies has changed from constructing new roads to preserving the ones that already exist (Gao and Zhang 2008). The Utah Local Technical Assistance Program (LTAP) assists local agencies in Utah and surrounding states to implement and use tools to maintain, preserve, and enhance their road and street facilities and more effectively manage the allocation of funding as it pertains to the existing street network. The strength of the pavement management system methodology implemented by Utah LTAP is that can be used effectively by many county and local governments with limited budgets and staff to manage their pavement systems. This is extremely valuable as for most, like the City of Tooele, the most valuable infrastructure
assets are the 144 miles (231 km) of streets within its network. Maintaining the street network at a high level of service will promote the prosperity of Tooele’s entire community and provide a conduit for economic growth.

This research will present the Utah LTAP pavement management methodology, data collection process, pavement distress survey, development of recommended strategies, data analysis, and the conclusion obtained. The research shows how local governments can manage their pavement streets network in a cost effective and efficient manner given limited budget and staff. Likewise, it is shown how the Utah LTAP pavement management methodology provides a way to predict pavement deterioration.

This prediction process applied to Tooele is then compared with historical data. Finally, the research suggests how local governments can use simple, yet effective pavement management systems and software applications to better manage their pavement network.

3.1 Road Condition Assessment

This section will describe characteristics of asphalt pavements, the data collection process, a description of the pavement condition survey employed, and the results of the Tooele pavement assessments in the years 2000, 2004, and 2009.

3.1.1 Asphalt Pavement Service Life Characteristics

Typically, asphalt pavements designed in accord with the AASHTO Guide for Design of Pavement Structures ought to provide for twenty years of traffic loading (18 kip ESAL’s) before reaching a terminal serviceability level at which point reconstruction
is required, that is, Remaining Service Life (RSL) is 0 years. Conventional practice usually provides for preventative maintenance and rehabilitative treatment to be applied to the asphalt pavement during its 20-year service life. Timing is critical in the placement of the preventative maintenance and the rehabilitative treatment to achieve the best level of service at the least amount of cost.

Figure 3.1 shows the typical pavement performance curve for asphalt pavements. This figure emphasizes the time relationship between street pavement condition and the cost of repair.

![Pavement Performance Curve](image)

**FIGURE 3.1** Pavement Performance Curve (Utah LTAP Pavement Analysis and Recommendations Report, 2010)

After eight years of service (RSL=12), most asphalt and concrete pavements will deteriorate to a "good" condition. This relates to a 40% drop in the service life of the
pavement and is the optimal point in time at which a preventative maintenance treatment should be placed. After twelve years of service (RSL=8), most asphalt and concrete pavements will deteriorate to a “fair” condition. This represents a 60% drop in the service life of the pavement and is the best point in time at which to consider a rehabilitation treatment. If no renovation action occurs at this point, the street will likely deteriorate to the "poor" category within three years (RSL=5). Cost comparisons show that reconstruction costs three to five times more than rehabilitation strategies. The cost to maintain a pavement with preventative maintenance strategies relates to about one-third the cost of rehabilitation strategies, or one-sixth the cost of reconstruction.

### 3.2 Data Collection Process

Tooele asked the Utah LTAP center to develop a pavement management system that could be used in their transportation plan. The pavement management system performed by Utah LTAP provides:

- A complete GIS-based physical inventory and condition survey of the street network
- A needs assessment process
- Analyses of the root causes of pavement deterioration
- Analysis of current street maintenance programs
- Recommended maintenance and preservation treatments
- Treatment costs and budget proposals
- A method to evaluate alternate funding scenarios to maximize the average RSL of the street network
Figure 3.2 outlines the major elements and processes incorporated in LTAP’s Pavement Management System. The following sections of this report describe each step of the process in detail, the results of field surveys and analyses, and the conclusions and recommendations offered to assist in the full implementation of the system in a given city. LTAP follows this process with every city to maintain consistency in the data collection and to establish a general procedure.

![Figure 3.2 Pavement Management Process Diagram (Utah LTAP Pavement Analysis and Recommendations Report, 2010)]
A complete condition survey of Tooele’s road network was conducted in three different years: 2000, 2004, and 2009. Employees from the Utah LTAP Center used the Strategic Highway Research Program (SHRP) Distress Manual as a guide to conduct the pavement distress survey. Inventory details include street name, starting and ending addresses of the segment, functional classification, segment width and length, estimated remaining service life, surface area of the pavement in square yards, and the percent of network area represented by each segment.

This inventory excludes pavement structure details regarding date of initial construction, layer thickness, and pavement design criteria of each street. This information can be obtained from historical records, maintenance personnel, or sampling and testing of the pavement structure.

3.3 Pavement Condition Survey

Complete windshield condition surveys were conducted covering the following areas: surface smoothness, drainage, and pavement distress. Employees from the Utah LTAP Center developed the methodology utilizing the Strategic Highway Research Program (SHRP) manual, *Distress Identification Manual for the Long-Term Pavement Performance Project*. The principal focus of the condition survey was to visually identify and determine the severity level and extent of each distress type by evaluating the road surface while driving at a low speed throughout the road segment. Additionally a representative picture corresponding to each segment was taken for reference of its visual condition. Each asphalt street segment was closely surveyed with respect to potholes/utility cuts, rutting, transverse cracking, longitudinal cracking, block cracking,
edge cracking, and fatigue (alligator) cracking. The severity level and extent of each distress type were evaluated in accord with the condition survey evaluation sheet shown in Figure 3.3.

The predominant asphalt pavement distresses affecting roadways can be determined from the pavement distress survey. Analysis of this information showed that there were eight major distress types prevalent in the street network. Pavement roughness results from these distresses. Fatigue cracking is the major distress type found occurring most frequently in the street network.

The first step in the analysis of the pavement distress survey information involved determining what the governing distress type is for each street segment. This requires analysis of each condition rating sheet to determine which distress type is rated the highest with regard to severity and extent.
FIGURE 3.3 Condition Rating Sheet (Utah LTAP Pavement Analysis and Recommendations Report, 2010)
Once the governing distress is determined, reference is made to the respective distress table that shows the condition rating value and its corresponding estimated remaining service life. Included in the table are the recommended preservation strategy and the recommended treatment that is most cost effective in correcting the governing distress. This is shown in Table 3.1.

Table 3.1 shows the distress table corresponding to fatigue cracking. The highlighted row in Table 3.1 shows a severity and extent rating of 5, which corresponds to a remaining service life (RSL) of 6 years. Because the 6-year RSL was the lowest RSL among the different distress types shown in Figure 3.3 (after checking each individual Distress Table), fatigue cracking is considered the governing distress for the street segment. The governing distress is the distress most likely to cause the pavement to deteriorate the soonest and reduce the service life of the street.

**TABLE 3.1 Fatigue Cracking Distress Table**

<table>
<thead>
<tr>
<th>Rating</th>
<th>Severity and Extent</th>
<th>RSL</th>
<th>Strategy</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No Alligator Cracking</td>
<td>20</td>
<td>No Maintenance</td>
<td>No Maintenance</td>
</tr>
<tr>
<td>1</td>
<td>Low, Low</td>
<td>10</td>
<td>Routine</td>
<td>Patch</td>
</tr>
<tr>
<td>2</td>
<td>Low, Medium</td>
<td>8</td>
<td>Rehabilitation</td>
<td>Thin Hot Mix Overlay (&lt;2 in)</td>
</tr>
<tr>
<td>3</td>
<td>Low, High</td>
<td>6</td>
<td>Rehabilitation</td>
<td>Thin Hot Mix Overlay (&lt;2 in)</td>
</tr>
<tr>
<td>4</td>
<td>Medium, Low</td>
<td>8</td>
<td>Rehabilitation</td>
<td>Thin Hot Mix Overlay (&lt;2 in)</td>
</tr>
<tr>
<td>5</td>
<td>Medium, Medium</td>
<td>6</td>
<td><strong>Reconstruct</strong></td>
<td><strong>Thick Overlay (3 in)</strong></td>
</tr>
<tr>
<td>6</td>
<td>Medium, High</td>
<td>4</td>
<td>Reconstruct</td>
<td>Rotomill &amp; Thick Overlay</td>
</tr>
<tr>
<td>7</td>
<td>High, Low</td>
<td>6</td>
<td>Reconstruct</td>
<td>Thick Overlay (3 in)</td>
</tr>
<tr>
<td>8</td>
<td>High, Medium</td>
<td>2</td>
<td>Reconstruct</td>
<td>Cold Recycle &amp; Overlay (3 in)</td>
</tr>
<tr>
<td>9</td>
<td>High, High</td>
<td>0</td>
<td>Reconstruct</td>
<td>Base/Pavement Replacement</td>
</tr>
</tbody>
</table>
3.4 Database

The database plays a key role in the use of PMS. The database not only contains all the collected information but it also allows the use of queries. Furthermore, the database contains different information associated with the local agency where the inventory is being performed such as treatment options, their associated costs, and RSL improvement related to each treatment option. For instance, this information is shown in Table 3.2, which is a sample database used within a city. By modifying some elements in this table we can add new treatment alternatives, modify current costs associated with the treatments, or modify the estimated improvement of RSL in each RSL category associated with each treatment.

Table 3.2 Customized database from within TAMS

<table>
<thead>
<tr>
<th>Treatment Type</th>
<th>Maintenance</th>
<th>Treatment Cost</th>
<th>RSL ADD 0</th>
<th>RSL ADD 1</th>
<th>RSL ADD 4</th>
<th>RSL ADD 7</th>
<th>RSL ADD 10</th>
<th>RSL ADD 13</th>
<th>RSL ADD 16</th>
<th>RSL ADD 19</th>
</tr>
</thead>
<tbody>
<tr>
<td>Routine Maintenance</td>
<td>Routine</td>
<td>$0.00</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Contracted Crack Seal</td>
<td>Routine</td>
<td>$0.10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>WVC C.S (Materials Only)</td>
<td>Routine</td>
<td>$0.20</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>WVC Slurry MAT. ONLY!</td>
<td>Preventative</td>
<td>$0.45</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Crack &amp; Slurry Seal</td>
<td>Preventative</td>
<td>$0.65</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Crack, R &amp; R and Slurry Seal</td>
<td>Preventative</td>
<td>$0.75</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>SLCC C.S w/Fog Coat</td>
<td>Preventative</td>
<td>$1.35</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>C.S &amp; C.S w/Fog (SLCnly)</td>
<td>Preventative</td>
<td>$1.45</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>PMSC (popcorn)</td>
<td>Rehabilitation</td>
<td>$1.91</td>
<td>0</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Overlay (2 in)</td>
<td>Rehabilitation</td>
<td>$5.04</td>
<td>0</td>
<td>4</td>
<td>6</td>
<td>7</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Asphalt CP &amp; Overlay (2 in)</td>
<td>Rehabilitation</td>
<td>$5.50</td>
<td>0</td>
<td>4</td>
<td>7</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Leveling &amp; Overlay (2 in)</td>
<td>Rehabilitation</td>
<td>$6.00</td>
<td>0</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Fabric w/ (2 in.) Overlay</td>
<td>Rehabilitation</td>
<td>$6.40</td>
<td>0</td>
<td>4</td>
<td>6</td>
<td>7</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Thick Overlay (3 in.)</td>
<td>Reconstruction</td>
<td>$6.60</td>
<td>2</td>
<td>4</td>
<td>7</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Cold Plane &amp; Thick Overlay (3 in.)</td>
<td>Reconstruction</td>
<td>$7.50</td>
<td>2</td>
<td>4</td>
<td>7</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Fabric w/ (3 in.) Overlay</td>
<td>Reconstruction</td>
<td>$7.85</td>
<td>2</td>
<td>4</td>
<td>7</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>In Place Base Rehab. &amp; Over (3 in.)</td>
<td>Reconstruction</td>
<td>$8.00</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>IF Base Rehab, Treat &amp; Over (3 in.)</td>
<td>Reconstruction</td>
<td>$8.48</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Silder Base Replace &amp; Over (6/3 in.)</td>
<td>Reconstruction</td>
<td>$12.50</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>Base (8 in.) / Pave Replace (3 in.)</td>
<td>Reconstruction</td>
<td>$13.50</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Base (12 in.) / Pave Replace (6 in.)</td>
<td>Reconstruction</td>
<td>$20.00</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>
3.5 Tooele Road Condition Surveys

Road conditions surveys for Tooele were conducted in the years 2000, 2004, and 2009. These surveys provided the information used in the Utah LTAP pavement management software for the development of a pavement management system for Tooele.

3.5.1 Year 2000

The procedure presented above was used to determine the governing distress and the RSL for each asphalt segment. When the road condition inventory was performed in 2000, Tooele’s street network condition had an average RSL of 10.8 years with about one percent of their street network at terminal serviceability. However, a relatively large percentage of the network (25%) was in the 4-6 year RSL category as seen in Figure 3.4. To prevent that portion from further deterioration, a pavement preservation strategy was developed using the Utah LTAP Pavement management software.

The following form shown in Figure 3.4 was used in the development of the preservation strategy which allowed engineering judgment to be utilized as well as an easy-to-use interface. As shown in Figure 3.4, the person in charge of the preservation strategy development inputs how much percentage of the total pavement network to be treated with a specific preservation strategy. Likewise, the software immediately calculates the needed road funding in order to apply such treatments to the desired amount of the road network. Additionally, the initial road condition distribution is shown as well as how the road condition will be in the following years if the preservation strategy is implemented. Also, it is important to notice that the software assumes that one
third of each RSL category deteriorates to the immediate category below (i.e. in year 2009 one third of the 2.56% roads in the 1-3 category will deteriorate to the 0 category assuming no treatment is applied) since each RSL category contains 3 years.

![FIGURE 3.4 Funding Allocation Form](image)

The form shown in Figure 3.4 is linked with the corresponding database where customization and information updates can be easily done such as updating the different treatment costs, improvement in RSL corresponding to each treatment, etc.

The target budget allocation of $400,000 was achieved and the software predicted a slight improvement in the pavement condition by the end of the recommendation period. The funding distribution used in the year 2000 is shown in Table 3.3.
3.5.2 Year 2004

When the road condition inventory was performed in 2004, Tooele’s street network condition had an average RSL of 10.4 years with about two percent of their street network at terminal serviceability. However, a relatively large percentage of the network (19%) was in the 4-6 year RSL category as seen in Figure 3.5. To prevent that portion from further deteriorating, a pavement preservation strategy was developed using the pavement management software. The available budget for year 2004 was $1,000,000. The preservation strategies were divided into two steps. Step one for the first year 2004-2005 and step two for the following years 2005-2009. The funding distribution for both steps meets the budget limitation as shown in Table 3.4.

**TABLE 3.3 Paved Road Funding Distribution 2000-2004**

<table>
<thead>
<tr>
<th>Pavement Preservation Strategies</th>
<th>Percent of Street Network</th>
<th>Funding Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Routine Maintenance</td>
<td>10.0%</td>
<td>$23,972</td>
</tr>
<tr>
<td>Preventative Maintenance</td>
<td>18.0%</td>
<td>$319,309</td>
</tr>
<tr>
<td>Rehabilitation</td>
<td>0.3%</td>
<td>$22,054</td>
</tr>
<tr>
<td>Reconstruction</td>
<td>0.3%</td>
<td>$35,958</td>
</tr>
<tr>
<td>TOTAL</td>
<td>28.5%</td>
<td>$401,293</td>
</tr>
</tbody>
</table>

**TABLE 3.4 Paved Road Funding Distribution 2004-2009**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percent of Road Network</td>
<td>Funding Distribution</td>
</tr>
<tr>
<td>Routine Maintenance</td>
<td>4.2%</td>
<td>$59,952</td>
</tr>
<tr>
<td>Preventative Maintenance</td>
<td>13.9%</td>
<td>$402,064</td>
</tr>
<tr>
<td>Rehabilitation</td>
<td>0.0%</td>
<td>$0</td>
</tr>
<tr>
<td>Reconstruction</td>
<td>0.6%</td>
<td>$536,554</td>
</tr>
<tr>
<td>TOTAL</td>
<td>18.69%</td>
<td>$998,570</td>
</tr>
</tbody>
</table>
3.5.3 Year 2009

In 2009, the processes were modified to support a finer level differentiation. For management purposes, the estimated RSL values were grouped incrementally into three-year categories. Figure 3.5 shows the current RSL distribution (May 2009) for Tooele’s street network in terms of percent of surface area of the network. The estimated average remaining service life of Tooele’s street network is 11.4 years. This average remaining service life value is similar to many cities surveyed to date by the Utah LTAP Center.

Currently, Tooele’s paved street network is in “good” condition. 0.3% of the network is at a terminal serviceability level as shown in Figure 3.4. If no preservation or rehabilitation work is undertaken, the software predicts another 7.6% can be expected to deteriorate to a terminal serviceability level in 3 years. On average, each street segment...
will most likely lose one year of service life per year without some preservation work being done. Within three years, if no pavement preservation is performed, about 32% of the asphalt paved network will probably deteriorate to a poor condition. This could place a major financial burden on the city to reconstruct these segments to provide adequate roads, as well as reduce the amount of public content with the street network. If a systematic pavement management program is implemented now, a balanced set of preservation strategies (e.g., routine maintenance, preventative maintenance, rehabilitation, and reconstruction) can be used to preclude the development of a backlog of needs and the overall decline in the service life of the network.

### 3.6 Development of Preservation Strategies and Recommended Treatments

Tooele City’s 2009 remaining service life distribution was shown in Figure 3.5. The average remaining service life for Tooele City’s paved street for 2009 is estimated at 11.4 years with 0.3% of the street network at a terminal service level. This qualifies Tooele as a candidate for benefit from a pavement management plan as the survey indicates a condition that exceeds the general threshold requirements of a minimum 10 years remaining with no more than 3% at RSL=0. At present, if no maintenance is performed on the street network, the number of streets at a terminal service level (RSL=0) is expected to increase from 0.2% to about 8% by 2012 and to about 40% by 2018. The resulting estimated average remaining service life for the year 2012 is 8.3 years, and for the year 2018 is 3.8 years.

As a first step in to progression to a preservation strategy, the governing distress types for each street segment is determined allowing pavement preservation strategies
and treatments to correct or remove the root causes. Frequently, more than one strategy or treatment can be used to cost effectively remedy the governing distress and other accompanying distresses that may exist. As an example, the distress deterioration table for fatigue cracking is shown in Table 1. This table shows the various combinations of severity and extent (rating) levels that may occur, along with their preservation strategies and recommended treatments. The corresponding estimated remaining service life of each rating level is also shown.

A second step is the generation of unit cost estimates for the treatment options. The unit costs used in the Tooele study were provided by the Utah Department of Transportation (UDOT) and are based on the average costs per square yard. A special inventory form built within the software program facilitates the analysis process and allows engineering judgment to be exercised at any point. This form is shown in Figure 3.6. The program uses the previously entered distress information to determine appropriate treatments.

On the left side of the form, inventory information pertaining to the street segment is shown. This information includes the address and location of the segment, surface type, number of lanes, length, width, area, posted speed limit, and date inventoried. On the right side, the various distress ratings are listed, along with a recommended preservation treatment. The “View Picture” button allows the user to look at a digitized photograph of the street segment.

The program provides valuable insight into the distresses affecting street segments and the corresponding pavement condition. The program should not be used indiscriminately in selecting pavement treatments. In order to be the most effective, the
program must be combined with good engineering judgment and project level field inspections to make project level analyses. This can be achieved by properly populating the form shown in Figure 3.6 with by using the software’s input as well as the corresponding engineering judgment. The program should be considered a tool, which the pavement manager can use to improve their decision-making skills not replace them.

**FIGURE 3.6** Utah LTAP Pavement Inventory Form
As a result of the assessment, a two-step treatment plan was generated. The first step in the recommended pavement preservation program deals with the years 2009 to 2012. A high percentage of preventative and routine maintenance with some rehabilitation and reconstruction treatments are recommended to decrease the percentage of roads in the “poor” category. Some of the preventative maintenance and rehabilitation strategies are to be applied at less than optimal points in time in order to buy time and move the needs of the road network from reconstruction to preventative maintenance.

The baseline funding for step one (2009-2012) is estimated to be $1,852,526 per year. It is important to note that if a higher amount of money is allocated initially to the asphalt network, it will require less to maintain later. The second step deals with the years 2012-2015. The baseline funding for step two is estimated to be $2,186,524 per year. The recommended funding distribution for the four pavement preservation strategies is given in Table 3.5.

Note that, for the 2009-2012 period, although only 4% of the whole road network is recommended to use Rehabilitation Strategies. This accounts for about twice of the money allocated towards preventative maintenance, which is recommended to treat 16% of the road network. With the implementation of the pavement management program the resulting remaining service life distributions for both step one and step two in 2012 and 2015 respectively are shown in Figure 3.7.
TABLE 3.5 Paved Road Funding Distribution

<table>
<thead>
<tr>
<th>Pavement Preservation Strategies</th>
<th>2009-2012</th>
<th>2012-2015</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percent of Road Network</td>
<td>Funding Distribution</td>
</tr>
<tr>
<td>Routine Maintenance</td>
<td>15.00%</td>
<td>$109,436</td>
</tr>
<tr>
<td>Preventative Maintenance</td>
<td>16%</td>
<td>$550,972</td>
</tr>
<tr>
<td>Rehabilitation</td>
<td>4%</td>
<td>$1,108,948</td>
</tr>
<tr>
<td>Reconstruction</td>
<td>0.20%</td>
<td>$83,171</td>
</tr>
<tr>
<td>TOTAL</td>
<td>35.20%</td>
<td>$1,852,526</td>
</tr>
</tbody>
</table>

FIGURE 3.7 Remaining Service Life Distribution after Following Recommended Treatments
Figure 3.7 shows a decrease in percentage of roads in the “0”, “4-6” and “7-9”, an improved remaining service life distribution, and an increase in the estimated average remaining service life to 13.9 years. The improved remaining service life distribution allows the road network to be maintained by strategies that are more cost effective.

The recommended two-step pavement preservation program uses strategies and treatments that are applied at points in time that are the most cost effective, that is, applying these treatments on a yearly basis throughout the different service life categories before more expensive treatments are needed as well treating the road network with as much preventative maintenance as possible rather than full reconstruction in order to get the most improvement of RSL per each dollar spent. Routine maintenance strategies are recommended to treat 15% of the asphalt road network in step one with crack seal. Other routine maintenance can be supplemented in as needed. Preventative maintenance strategies are recommended to treat 16% of the road network with slurry seals. Other preventative maintenance can be supplemented as needed. For roads requiring rehabilitation, thin hot mix overlay (<2in.) is recommended. For roads requiring reconstruction, thick hot mix overlay is recommended.

The remaining service life of the Tooele’s road network has changed from 10.8 to 10.4 to 11.4 during the years the pavement inventories were performed by Utah LTAP. The pavement life performance has changed throughout these years as can be seen in Figure 3.8.
Between 2000 and 2004 the remaining service life of the street network slightly deteriorated from 10.8 to 10.4. However, Utah LTAP has been working closely with the Tooele public works and getting updates when there are treatments applied through the road network. In year 2000, after the first inventory, Tooele invested in pavement overlays. Tooele public works director reported that such overlay work was faulty (low density achieved) and this resulted in a lower remaining service life for the road network in 2004. Between 2004 and 2009 there is an improvement in the remaining service life of the street network from (10.4 to 11.4). Especially a reduction in the “0”, “1-3” and “7-9” remaining service life categories which results in more cost effective treatment options for future pavement maintenance. Overall, between 2000 and 2009, the remaining service life has improved from 10.8 to 11.4. Also, Figure 3.8 shows that the number of roads in

FIGURE 3.8 Remaining Service Life History for Tooele
the failed and poor categories (RSL from 0 to 6), have been greatly reduced and therefore future repairs will be less expensive since the higher-remaining service life road network can be treated using more routine and preventative maintenance techniques, which are much cheaper than rehabilitation and reconstruction techniques.

There is one strong reason for the better money allocation. Generally local governments without the use of a pavement management system allow their roads to deteriorate to a poor condition before any preservation is applied. These roads will need to be treated with costly rehabilitation or reconstruction strategies. However, the software recommendations are based on the idea that it is more cost effective to treat the roads with less substantial but more frequent treatments. That proves to be more cost-effective. For instance preventative maintenance not only keeps the roads in good condition but also increases the most serviceability (RSL) of the roads per dollar spent on it.

The use of the Utah LTAP pavement management software, the software used by the Utah LTAP, was crucial on achieving such pavement condition improvement because of the appropriate cost-effective treatment recommendations given to Tooele despite its limited budget.

3.7 Geographic Information System

Another special feature of TAMS is the use of geographic information systems (GIS) within the software. This allows the users to be able to view the data collected graphically, which helps to better understand such data. Also, the use of GIS allows the user to select any road shown in the map by clicking on it, which brings up the road’s information form previously shown in Figure 3.6. Furthermore, the use of GIS within the
software provides useful features, such as printing maps, which show the road’s condition and/or the optimal treatment for specific road segments throughout the agency’s road network. This is shown in Figure 3.9.

![TAMS GIS based road network map](image)

**Figure 3.9.** TAMS GIS based road network map

Figure 3.9 also shows different tools characteristic of GIS based software. The icons shown are: Add new layer, zoom, pan, global zoom, identification, labeling, etc.
3.8 Importance of Feedback

The pavement preservation program requires accurate and timely feedback on all decisions and actions taken with respect to preservation (routine maintenance, preventative maintenance, rehabilitation maintenance, and reconstruction) of each street segment. This feedback should include such information as type of work performed, unit costs of work items, amount and quality of work performed, date of completed work, additional pavement structure added, and any other design related information. In addition, periodic condition surveys should be made to keep track of the condition of each street and the network as a whole. These periodic condition surveys should be conducted every 2 to 3 years. This feedback information will enable the pavement management team to fine-tune the pavement management computer program providing better information to decision-makers at all levels.

Any pavement management system must have a means of keeping accurate, up-to-date information about the condition and inventory of the street network. Good decisions are difficult to make without such information. The Transportation Asset Management System (TAMS) computer program provided by the Utah LTAP Center makes this process easy for users.

This computer program allows for the inventory of current distress information, tracking of treatments applied, history of work done, and cross section information via pictures of the street segment. These tools provide valuable information that can assist in better decision-making regarding the allocation of resources to maintain and preserve the street network. Figure 3.10 shows the forms used for inventorying and updating the street network.
3.9 Economic Analysis:

An economic analysis of three different preservation strategies was conducted supporting evaluation and comparison for Tooele’s road network generating an analysis that provided a better understanding of the correlation between the cost, the benefits, and time. Some of the key assumptions and parameters utilized were:
Evaluation over a 40-year period, twice the average service life of a newly constructed pavement road.

Full road reconstruction costs were estimated at $20/sq yd, rehabilitation treatment (cape seal) costs at $2.34/sq yd and preventative maintenance (microsurfacing) costs at $1.44/sq yd.

The road network consists of 2,918,283 sq yd.

A 3% inflation rate

The pavement live cycle curves in Figure 3.1.

Option 1 consisted of applying complete base and pavement replacement after the road completely fails and no other preservation would be very effective. This option is expected to last for 12 years if no treatment is applied throughout the life of the pavement.

Option 2 consisted of applying preventative treatment 8 years after newly constructed road at the optimal time to apply such preventative treatment. After six more years, complete base and pavement replacement is applied.

Option 3 consisted of getting the most use of rehabilitation and preventative treatments, applying preventative treatment eight years after the road network is newly constructed. Rehabilitation treatment is applied four years after the preventative treatment. Then, after eight more years, complete base and pavement is applied.

The results of this simple, yet representative economic analysis are shown below:

Option 1 is the least cost-effective strategy having the lowest Net Present Value (-$75,590,602)
• Option 2 is more cost-effective than option 1 and has a higher Net Present Value (-$66,506,071)

• Option 3 is the most cost-effective option and has the highest Net Present Value (-$43,603,093)

In using the Net Present Value method, the researchers noted that there may be cases in which a positive net present value is not available within the range of possible solutions in which case the least negative value is the best available option. This is the case in the Tooele example. The analysis concludes that by using strategies where preventative maintenance treatments are applied at optimal times, pavement life can be greatly extended and thus costs can be greatly reduced.

3.10 Summary and Conclusions

This chapter presents a real example of how useful a Pavement Management System can be for a local agency. The example shows how a pavement management system helped Tooele, Utah’s road network be better maintained. The inventory process explained shows how the data was collected, the criteria used in the road condition rating, and the software capabilities that were used. Additionally, the data obtained from previous road condition surveys conducted in previous years was analyzed. Furthermore, the different software’s capabilities and useful features are explained. Some of these are: GIS capability, funding allocation form, database capability, condition rating sheet, Money allocation form, network RSL prediction.

A simple yet illustrative economic analysis is shown in order to explain the economic impact that different pavement preservation strategies have. The three different
pavement preservation strategies were evaluated, the first one consisting of no preventative maintenance, the second one consisting of some preventative maintenance and the third one consisting of more preventative maintenance. The results as expected show that the road that is treated before deteriorates to a poor level by using preventative maintenance results in much cheaper costs over time.

The methodology presented in the chapter provides a simple but efficient way to manage pavement networks in a local level. The contribution of this research is the validation of the utility of simple methods that have been previously unavailable to smaller agencies. The simple, yet effective methods provide the key benefit of using pavement management software is being able to treat pavements before they need substantial treatment, therefore saving the local government money.
CHAPTER 4
CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusion

There has been extensive research on pavement management systems throughout the last decades. However, there is still a lack of a general procedure on pavement management systems and there is room for improvement in pavement management systems practice in a local level. This report presents an alternative procedure to pavement management systems developed by the Utah LTAP that has been successfully and extensively used throughout Utah and a few other states.

Additionally this report compares the Utah LTAP software with other PMS used in a local level thus identifying the strengths and weaknesses of these software and the features and capabilities that should be evaluated before making a decision on which PMS to implement within a local agency. This comparison shows that TAMS is the cheapest one and the most appropriate one for small agencies while Micro Paver is most appropriate for bigger agencies, due to its cost and complexity. Furthermore, this report shows some of the improvements that the new version of the Utah LTAP pavement management software made on its latest version which was released during the development of this report.

Additionally, a case study based on the use of the Utah LTAP pavement management software in Tooele City, Utah shows the benefits it had helping preserve the pavement network at Tooele City. This showed how the money was allocated throughout several years with the aid of the PMS. This case study also showed how the
implementation of the PMS was effective in extending the pavement network service life while having a drastic reduction in the total cost of pavement costs. An economic analysis of no pavement management, a partial pavement management system, and a full pavement management system are also provided. The full pavement management system showed a savings of about $32,000,000 over a 40-year period for the city when compared to a no maintenance option.

Local agencies are quite interested in saving money on their road network preservation. However these agencies often act in a corrective rather than preventive manner by repairing roads once they have fallen into a poor category. By better knowing how pavement behaves and by having appropriate pavement management system these agencies can better transition from a corrective to a preventive way of preserving their road network, thus saving money to their already limited budget.

4.2 Recommendations

The pavement management software presented can still be improved on future versions. A comprehensive feedback collection from all the different agencies officials and LTAP technicians that use the software should be analyzed and used towards development of new features and improvement of current ones. Some key points that should be looked into are:

- Work closely with agencies on the improvement of the pavement management system.
- Implement a more sophisticated (including more variables) yet still relatively simple prediction model within the software.
• Look for ways to allow the software to be more customizable and easy to adapt to different agencies since different agencies have a wide range of population and different characteristics (i.e. geographical, economic), needs and preferences.

4.3 Future Work

Future research should include improvement in the pavement prediction model for a PMS intended for use in a local agency. This research should focus on what affects roads in local agencies the most and provide for flexible ways to include this pavement prediction model into a PMS so that agencies will have the choice to use the factors that they want or have data available for in their respective pavement prediction model. This should be done keeping in mind that simplicity and user friendliness is necessary for this to be applicable in a local agency.
REFERENCES


Gao, L., and Z. Zhang. Robust Optimization for Managing Pavement Maintenance Rehabilitation. In Transportation Research Record: Journal of the Transportation


