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RESEARCH ARTICLE

Analysis of cost effective pavement treatment and budget optimization for arterial roads in the city of Chattanooga

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ABSTRACT Many transportation agencies lack sufficient funds to maintain and repair roads, which results into increased pavement maintenance cost. Pavement Management System (PMS) has demonstrated to be an essential tool for proper management of infrastructure and proper utilization of available funds. The University of Tennessee at Chattanooga utilized Micropaver software as PMS tool to conduct a pavement management analysis of principal arterials in the City of Chattanooga. The study used the City of Chattanooga pavement database to create the current and future pavement conditions. Maintenance and repair (M&R) planning analysis was also performed in order to determine the most cost-effective treatment and suggest the optimum utilization of funds for the city. An analysis of five budget scenarios was conducted for a five-year plan using the critical pavement condition index (PCI) method (ASTM D6433). Results show that the backlog elimination budget would be the best scenario because it increases the pavement condition and eliminates the backlog of major maintenance and repairs over the five-year period. The unlimited budget seems though ideal, it does not improve pavement condition. Maintaining current condition and limited budget scenarios would increase both the backlog and the total cost of maintenance and repairs over the analysis period.

KEYWORDS PMS, Micropaver, pavement budget, maintenance, rehabilitation

1 Introduction

The city of Chattanooga is located in southeastern Tennessee and has a population of 173,366 (State&County Quickfacts. U.S. Census Bureau, 2012). The road network of the city is comprised of 2311.15 lane miles of locally maintained paved roads, which includes 101.46 lane miles of principal arterials, 314.55 lane miles of minor arterials, 172.67 lane miles of collectors and 1722.46 lane miles of local roads. The annual average daily traffic (AADT) is distributed in such a way that principal arterials carry 24% of AADT, minor arterials carry 62% and the remaining percentage is carried by local and collector roads. This case study considered principal arterials for the analysis because they carry almost a quarter (24%) of the city's traffic (AADT), although they represent only 4.39% of the whole pavement network of the city.

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According to the pavement inspection performed by the city in year 2010, all roads were in good condition. The average pavement condition index (PCI) was 79.8, whereas the average condition of principal arterials was 82.7 (Table 1). Figure 1 illustrates the principal arterials condition distribution. It should be noted that, pavements that are currently in good condition are subject to deterioration. Consequently, if nothing is done in five to ten years, these roads will require more elaborated rehabilitation, such as resurfacing or reconstruction. This calls for proper allocation of the funds by utilizing PMS tools and cost-benefit analysis in order to improve pavement condition and performance.

2 Background and literature review

Pavement management system (PMS) as a decision-making tool is used to predict pavement maintenance

Table 1 Characteristics of the road network of Chattanooga

section rank	weighted average condition	lane miles	percent area (%)	number of sections	percent sections	average condition	average age at inspection
principal	82.4	101.46	4.39	201	2.27	82.76	8.98
minor	83.67	314.55	13.61	869	9.8	83.2	10.81
collector	80.34	172.67	7.47	526	5.93	78.82	12.58
local	75.26	1722.46	74.53	7273	82	74.42	14.88
total		2311.15	100	8869	100		

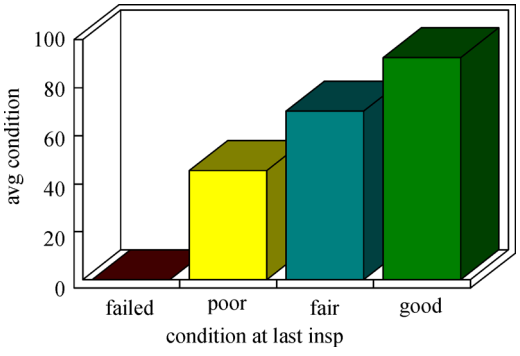

Fig. 1 Condition distribution of Principal Arterials at last inspection

and rehabilitation requirements in order to make optimal use of road maintenance funds [1]. The main objective is to preserve pavements in good condition rather than wait to reconstruct after major pavement failures [2]. Early investments in maintaining the integrity of roads will pay off over time, each dollar spent on maintaining roads in fair condition will forego the need to spend four to five dollars on rehabilitating or reconstructing a road that is in very poor condition (Fig. 2) [3].

In pavement management system, information about pavement condition must be collected, stored, analyzed and used for decision making. Visual and automated condition surveys are commonly used to determine the ride quality of pavement surfaces based on measuring indices such as the Pavement Serviceability Index (PSI) or Pavement Condition Index (PCI) in this case study. The Pavement Condition Index (PCI) method is used to assess and compare the overall condition of pavements.

PCI values are typically computed using a pavement management software package, such as Micropaver, among others. The PCI was used to assess the pavement condition of the City of Mandan, North Dakota [2] using Micropaver software. It was concluded that the total overall cost to the City is less if the major M&R backlog is eliminated over a five-year period. Figure 2 shows the benefit of performing maintenance and repair (M&R) before the condition drops too low. Ajay performed a PMS analysis using Micropaver for the University of Rhode Island [4]. He analyzed the future condition using the critical PCI in the form of a regression curve using family modeling along with an economic analysis. He showed the importance of pavement condition monitoring in PMS (Fig. 2).

Moazami et al. evaluated pavement condition in Iran, along with deterioration prediction models using the "family method" in Micropaver [5]. The models showed a deterioration trend for 10 families that correspond to 10 branches. Two budget scenarios: limited and unlimited were used for analysis. He concluded that the minimum annual budget for one of the ten branches studied should not be below the limited budget otherwise a rapid fall in overall condition will happen. Furthermore, the annual

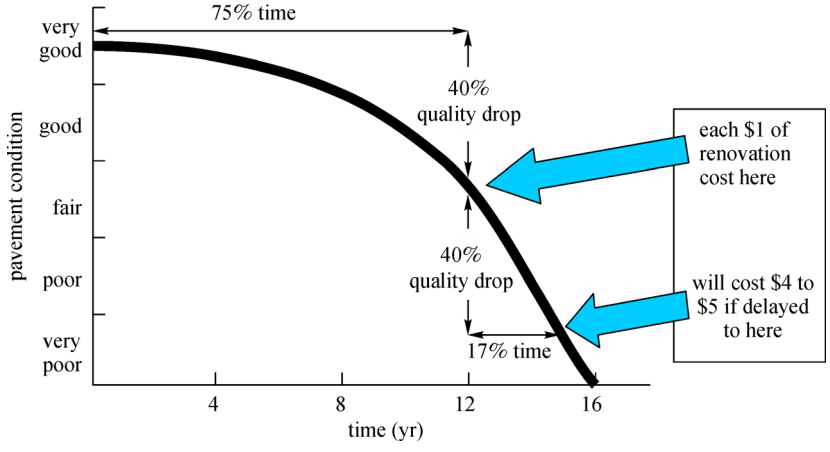

Fig. 2 Pavement deterioration/rehabilitation relationship

budget (limited) causes the average weighted PCI of two branches to fall below the critical PCI. In order to maintain the average current weighted PCI for all branches during the planning period, a certain investment was needed.

The City of Palm Spring California (2008) performed a budget analysis under the M&R plan, the City would require a budget $24.5 Million over 5 years (or $4.9 Million annually) just to ensure that the existing streets condition was maintained [6]. Kmetz evaluated 168 miles of the City of Westfield roads in Indiana using a program called PASER developed by the University of Wisconsin. He determined that the streets in the city were in good condition with over 80% of the roads having a PASER rating between 6 and 10 on a scale of 1 to 10, 1 being failed and 10 being excellent [7].

Sen studied the pavement management system using two software packages: Highway Development and Management System (Version 4) HDM-4 and Highway Pavement Management Application (HPMA) to find a cost-effective strategy to prioritize each Hamilton County interstates and state routes. This prioritization was accomplished based on the immediate maintenance needs required by the road sections. She also concluded that the two software programs could be used for PMS and maintenance prioritization, but the analysis is performed differently using the two software packages [8].

Rajagopal developed pavement performance prediction models for the city of Cincinnati, Ohio that can be used in conjunction with the pavement management system, along with a decision tree to suggest the appropriate maintenance and rehabilitation activities based on the current condition of the pavement [9]. This study used a similar approach, using Micropaver software to analyze the base condition and predict future condition of arterial roads for the city of Chattanooga.

3 Objective and methodology

The objective of this study was to perform an optimization analysis of arterial roads in the city of Chattanooga using Micropaver software, in order to properly utilize the limited available funding. The analysis took into account base year pavement condition and the maintenance treatments required to keep the pavements in a satisfactory condition. 28 branches comprising 201 sections were investigated. A branch is part of the pavement network or a single entity that has a distinct function (such as a street or a parking lot). A section is a division of a branch. It is the smallest management unit when considering the application of maintenance and rehabilitation (M&R) treatments. For a network analysis, seven deterioration prediction models were developed to analyze the present and predicted future pavement conditions. An Economic analysis was also performed to compare five different allocated budgets during the analysis period of five years.

4 Micropaver software

The Micropaver is a pavement maintenance management system software that was developed by the U.S. Army Corps of Engineers in the 1970's. It uses pavement condition inspection data and a pavement condition index (PCI) to describe the base year condition, predict future condition, determine its M&R needs, and decide where to best allocate the funds (Colorado State University. Paver™ Software, 2010). Micropaver provides engineers with a systematic approach for the determination of maintenance and rehabilitation needs and priorities for the projects [10]. The primary Micropaver modules include inventory and M&R history, inspection, prediction modeling, condition analysis, M&R planning, project planning and reporting. The Inventory module allows users to easily organize their inventory while providing numerous fields and levels for storing pavement data. The objective of the inventory module is to provide data for identifying the pavement's network, branches, and sections (Colorado State University. Paver™ Software, 2010).

In Field Inspection module, Micropaver uses the Pavement Condition Index (PCI) based on American Standards of Materials and Testing (ASTM D-6433-03). It is an overall indicator that measures pavement surface operational condition and structural integrity [11]. The PCI provides a numerical rating for the condition of road segments in a road network, where 0 is the worst possible condition and 100 is the best. If properly designed and constructed, a new pavement begins its service life with a PCI of 100. Due to the effects of loading and aging, a pavement deteriorates over time. For each combination of distress types, severity level, and quantity observed, points are deducted from 100, and its PCI decreases. The method has been field-tested and proven to be useful for determining M&R needs and priorities, as it is used by state DOT's including the state of Tennessee and has ASTM specification [2,4,5,8,12]. Pavement condition in the city of Chattanooga was categorized based on PCI values as shown in Table 2.

Prediction models are used to accurately predict the future performance of the pavements and for planning M&R requirements. Regression analysis is used to develop a separate prediction model for each group. The dependent variable is pavements condition index (PCI) and the independent variable is the corresponding number of years

Table 2 Pavement condition assessment criteria for the city of Chattanooga

condition category	PCI value
failed	0–20
poor	21–50
fair	51–80
good	81–100

since construction or resurfacing (age). The analysis in Micropaver allows users to view the condition of the entire pavement network or any specified subset of the network. Past conditions can be reported based on prior interpolated values between previous inspections. Future conditions can also be determined using created prediction models. This is used to plan future maintenance and repairs, and also it shows the consequence of not performing major repairs and justifies budget requests.

M&R work planning module is an elaborated tool for a multi-year network level and project level M&R planning, scheduling, budgeting, and identifying the optimum levels of pavement maintenance and repair activities for each section based on distress, current condition and rate of deterioration and the stored M&R policy. The work planner tool also identifies the year the work is required and estimate an M&R budget for each year. In addition to that, the ability to analyze the consequence of various budget scenarios on pavement condition is availed. These capabilities enable agencies to: 1) develop optimal M&R programs given available resources, and 2) justify optimal M&R budget needs.

5 Database

The pavement database of the road network of the city of Chattanooga was provided by the pavement department of the city of Chattanooga. The principal arterials data was selected for this case study. The roadway of the city is divided into pavement sections. Each section is defined by its surface type, address from/to locations, construction dates, maintenance and rehabilitation history, etc. The road network of the city is defined by sixteen sub-networks. The data used for the principal arterials comprise five sub-networks defined as follow (Table 3).

Network ID: COC-SA1-T1 is defined as city of Chattanooga-Service Area1-Team1, the rest of the list is defined in the same pattern. Each network ID comprises a number of branches and each branch contains few sections. There is 28 branches and 201 sections as shown in Table 3. The Annual Average Daily Traffic (AADT) is required for the creation of family models and it was obtained from Tennessee Department of Transportation (TDOT). Seven deterioration models were created based on seven families. Each family represents a group of branches with the same range of traffic count. An example of the trend of family 3 is presented in Fig. 3.

Table 3 Principal Arterials network characteristics

network ID	number of branches	number of sections
COC-SA3-T1	7	32
COC-SA3-T2	14	107
COC-SA4-T1	3	35
COC-SA4-T2	3	23
COC-SA4-T4	1	4
total	28	201

6 Results and analysis

The objective of this study was to perform an optimization of M&R of principal arterial in the city of Chattanooga, for proper allocation of available funding. The road network, base year pavement condition, and traffic data were used as inputs into the Micropaver software. Seven deterioration models for the seven families were used for the analysis. A 10-year condition analysis was performed on the network; if nothing is done the average pavement condition drops from 73.69 in 2015 to 62 in 2024. There will be 4% of the road network in failed condition in 2024, which requires higher rehabilitation cost.

In order to optimize the funding of M&R and maintain the road network pavement condition, the analysis was then performed with five different budget allocation

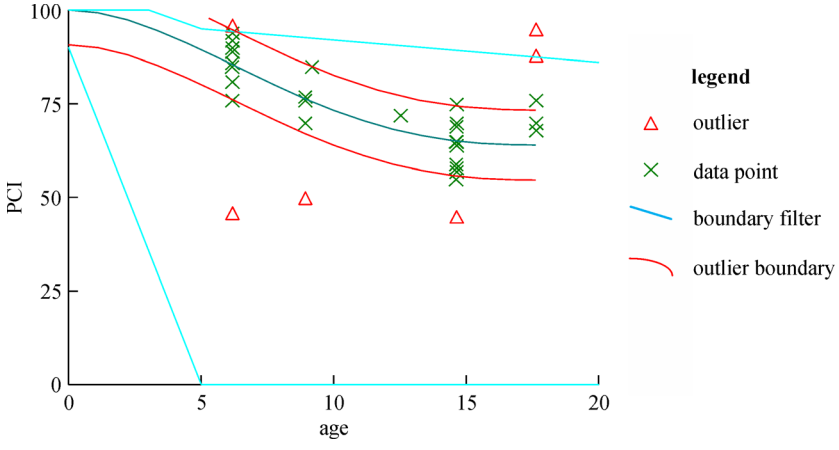

Fig. 3 Deterioration trend of family 3

scenarios, which are: limited budget of $132 k/yr, limited budget of $1 M/yr, unlimited budget, budget required for maintaining current condition, and budget required for backlog elimination. For each of these budgets, an economic plan was achieved as well as the backlog in funding.

The M&R budget analyses were performed on the database provided by the city. Micropaver uses among other things, critical PCI for prioritization of M&R and decision making. Critical PCI value of 55 was set for the analysis. The M&R policies and the rates of different works were taken as default from the Micropaver 6.5 along with an inflation rate of 3%. For each scenario, the PCI before and after M&R as well as the funding required for stopgap (safety M&R), preventive maintenance, major repair above the critical PCI, major repair under the critical PCI and the backlog of unfunded M&R are reported. Tables 4–8 show the funding results for each budget scenario [13].

6.1 Condition analysis

The 10-year network condition evaluation resulted in a decrease of PCI from about 73.69 in 2015 to about 62 in 2024 (an average of 1 point/yr). The current condition (in 2015) is shown in the bar graph (Fig. 4), 55 sections (27%) are in good condition, 132 sections (65%) are in fair condition, 16 sections (8%) are in poor condition, and no section (0%) are in failed condition. After performing the analysis and predictions for 10 years, by 2024, only 12 sections (6%) will be in good condition, 151 sections (74%) will be in fair condition, 32 sections (16%) will be in poor condition, and 8 sections (4%) will be in failed condition.

6.2 Maintenance and rehabilitation (M&R) planning: budget analysis

The main objective of M&R planning is to maintain the pavement in good condition, extend its life and reduce the major M&R backlog over time. In this perspective, the pavements are being managed as cost effectively as possible through preventive maintenance and infrequent rehabilitation projects. M&R plans were developed based on five different budget scenarios for a five years M&R budget analyses to determine the impact of different funding levels on the city's pavement condition: 1) limited $132 k/yr, 2) limited $1 M/yr, 3) unlimited, 4) budget required for maintaining current condition, and 5) budget required for backlog elimination. For each scenario, Micropaver outputs an economically viable work plan. After generating maintenance needs for the pavement sections for each budget scenario, Micropaver software makes a prioritized listing of M&R of pavement sections based on the sections PCI results and distresses information from the five years analysis (Tables 4–8) [13].

A limited budget of $132,000/yr (Table 4) results in a decrease in PCI from 73.64 in 2015 to 69.14 in 2019, and a backlog accumulation of unfunded M&R of $9 million in the last year. The prioritization results show that 9% of the sections will benefit from "stopgap" maintenance, 17% from "preventive" and the rest will not be repaired "do nothing" because it is impossible to allocate the budget to all sections. Some sections that need maintenance will be postponed to the next year as per the priority list.

A limited budget of $1 million/yr (Table 5) shows a slight increase in PCI from 73.64 in 2015 to 76.09 in 2019, the backlog accumulation of unfunded M&R is $4 million in the last year. The prioritization results at the first year show that 9% of the sections will benefit from "stopgap" maintenance, 74% from "preventive", and 5% from "major above critical" repairs, the remaining section's policy is "do nothing".

To eliminate the existing M&R backlog over the next five years it was determined that a budget of approximately $1.7 million/yr is needed. Table 6 shows an increase in PCI from 73.64 at the beginning of 2015 to 81.09 at the end of 2019 and 0.00 backlog accumulation. The prioritization results for the first year of repair show that 67% of the sections will receive "preventive" maintenance, 12% will not receive any repair, 12% will benefit from "major repair above critical", 9% will benefit from safety M&R or

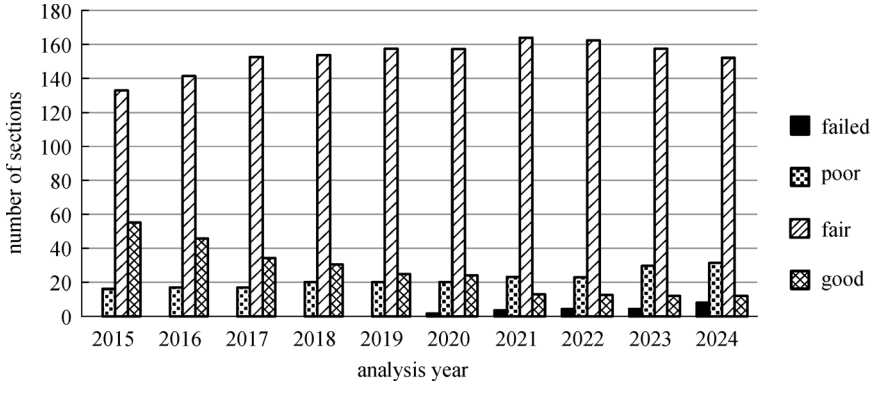

Fig. 4 Pavement condition prediction summary

Table 4 Scenario 1 – limited budget of $132,000/yr

plan year	PCI before	PCI after	stopgap funded	preventive funded	total funded	backlog accumulation at the last year
2015	73.64	73.66	$6,332	$125,666	$131,997	
2016	72.44	72.46	$7,667	$124,158	$131,825	
2017	71.29	71.31	$10,653	$121,118	$131,772	
2018	70.2	70.21	$16,327	$115,628	$131,955	
2019	69.12	69.14	$23,888	$107,749	$131,637	$9,333,485
			$64,869	$594,320	$659,189	$9,333,485

Table 5 Scenario 2 – limited budget of $1,000,000/yr

plan year	PCI before	PCI after	stopgap funded	preventive funded	major above critical funded	total	backlog accumulation at the last year
2015	73.64	75.05	$6,332	$254,897	$723,262	$984,492	
2016	73.8	75.27	$7,667	$261,565	$725,713	$994,946	
2017	74.02	75.47	$9,829	$269,757	$716,864	$996,451	
2018	74.25	75.74	$15,009	$257,412	$715,396	$987,818	
2019	74.46	76.09	$21,897	$279,450	$691,540	$992,888	$4,320,613
			$60,735	$1,323,083	$3,572,778	$4,956,596	$4,320,613

Table 6 Scenario 3 – backlog elimination budget

plan year	PCI before	PCI after	stopgap funded	preventive funded	major under critical funded	major above critical funded	total funded	backlog accumulation at the last year
2015	73.64	76.54	$6,332	$216,380	$0.00	$1,517,305	$1,740,018	
2016	75.26	78.49	$7,667	$199,037	$0.00	$1,524,417	$1,731,121	
2017	77.19	80.14	$8,093	$222,999	$697,402	$798,009	$1,726,505	
2018	78.65	80.72	$8,272	$236,228	$1,462,023	$0.00	$1,706,524	
2019	79.12	81.09	$0.00	$271,144	$1,430,881	$0.00	$1,702,025	$0.00
			$30,365	$1,145,790	$3,590,308	$3,839,732	$8,606,195	$0.00

Table 7 Scenario 4 – maintain current PCI budget

plan year	PCI before	PCI after	stopgap funded	preventive funded	major under critical funded	major above critical funded	total	backlog accumulation at the last year
2015	73.64	74.37	$6,332	$278,170	$0.00	$324,910	$609,413	
2016	73.13	73.82	$7,667	$306,229	$0.00	$299,641	$613,538	
2017	72.63	73.22	$9,829	$339,189	$0.00	$259,468	$608,487	
2018	72.04	72.58	$14,959	$348,081	$21,791	$225,079	$609,912	
2019	71.41	71.88	$21,844	$377,952	$0.00	$198,113	$597,910	
			$60,632	$1,649,622	$21,791	$1,307,214	$3,039,261	$8,154,952

"stopgap".

The total funded budget needed to maintain the average current weighted PCI in all branches was determined to be approximately $0.6 million/yr. This budget scenario results in a slight decrease in overall PCI from 73.64 to 71.88. M&R backlog on the last year is $8 million (Table 7). The prioritization results show that 9% of the sections will benefit from "stopgap" maintenance, 77% from "preventive", and 2% from "major above critical" 2% at first year, for the rest of the sections the policy is "do nothing".

With unlimited annual budget of $1.5 million/yr and $6 million to spend in the first year, results show that the weighted average PCI would increase from 73.64 in 2015 to 79.84 in 2016 and no backlog of M&R will accumulate in last year (Table 8). The prioritization results show that at the first year, 55% of sections will benefit from "preventive" maintenance, 25% from "major above critical", 8% from "major bellow critical", for the rest of

Table 8 Scenario 5 – unlimited budget $1,500,000/yr

plan year	PCI before	PCI after	preventive funded	major under critical funded	major above critical funded	total	backlog accumulation at the last year
2015	73.64	84.89	$154,126	$2,410,698	$3,691,142	$6,255,967	
2016	83.53	83.69	$186,457	$0.00	$0.00	$186,457	
2017	82.11	82.26	$222,999	$0.00	$0.00	$222,999	
2018	80.55	81.25	$236,228	$379,874	$0.00	$616,102	
2019	79.53	79.84	$271,889	$64,573	$0.00	$336,463	
			$1,071,701	$2,855,146	$3,691,142	$7,617,990	$0.00

the sections the policy is "do nothing". In this scenario, M&R expenditure is optimized by using the M&R pavement section assignment such as if the section PCI is equal or above critical apply localized or global preventive. If section PCI is bellow critical PCI, localized safety or major M&R is applied.

The economic consequences of each annual budget scenario are summarized in Table 9. Considering that both annual M&R expenditures and the remaining M&R backlog are treated as costs incurred by the city, then the total overall cost to the city is less if the city eliminates its backlog with a budget of $1.7 million/yr. The unlimited budget would be the ideal but requires to spend 6 million dollars in the first year which is not available. It is not possible to achieve a perfect network because each year the percentage of PCI on streets will drop because of the usage. If it is determined that the network PCI should be maintained at the current level, then we have the consequence of maintaining current PCI option to be able to show the cost required to maintain. If it is determined that there is a limited budget each year, then the consequences of the budget restriction are shown as long as the best benefit is achieved with the lowest cost (B/C).

7 Conclusions

This case study was performed using the Micropaver Pavement Management System software to determine a cost-effective maintenance and rehabilitation policy for principal arterials in the city of Chattanooga. Seven deterioration models were created to predict the condition of individual pavement sections. Results indicated that weighted PCI decreases from about 73.69 in 2015 to about 62 in 2024 assuming no major M&R are performed. The overall pavement condition is fair during the 10 years and 4% of the roads in the network will be in the failed condition at the end of the 10-year period

The budget analysis was conducted using five different budget scenarios with the objective to maintain a satisfactory overall pavement condition and reduce major M&R funding backlog over time (Figs. 5 and 6). Each budget scenario gives a cost-effective work plan, and maintenance needs generated for the 201 sections.

From the analysis, the ideal budget scenario is the backlog elimination over five years. This budget eliminates the M&R funding backlog and improves the pavement condition. The unlimited funding of $1.5 million/yr eliminates the backlog in the 5 years but the weighted PCI is slightly decreased. This budget also comes with a $6 million investment in the first year, which is impossible for many cities to acquire. Other scenarios will have the unfunded M&R backlog, which in the long run ends to be more costly (Tables 9 and 10).

Nevertheless, the economic consequence of the five budget scenarios is that it gives options to the city to choose from according to the available funds. Each budget scenario gives a different choice for the city's pavement management based on available funds and either engineering decisions or political decisions. The idea is to get the best benefit, which is increasing the PCI over the analysis period at the lowest cost possible.

M&R expenditure is optimized by using the M&R pavement section assignment such as if the section PCI is

Table 9 Summary of estimated five-year pavement major M&R budget costs

budget scenario	total five-year M&R costs (2015−2019)	remaining M&R backlog (2019)[1)]	total five year costs[2)]	cost differential
unlimited $1.5 million	$7,617,990	$0	$7,617,990	baseline
backlog elimination $1.7 million	$8,734,624	$0	$8,734,624	$1,116,634
limited budget $1million	$5,000,000	$4,320,613	$9,320,613	$1,702,623
limited budget $132 thousand	$660,000	$9,333,485	$9,993,485	$2,375,495
maintain current PCI $0.6 million	$3,681,424	$6,831,526	$10,512,950	$2,894,960

1) "M&R Backlog" equals the lump-sum cost to resurface/reconstruct all pavements at or below the critical PCI value. 2) "Total five years cost" equals the sum of the five years Major M&R expenditures plus the remaining Major M&R backlog at the end of the five years analysis period.

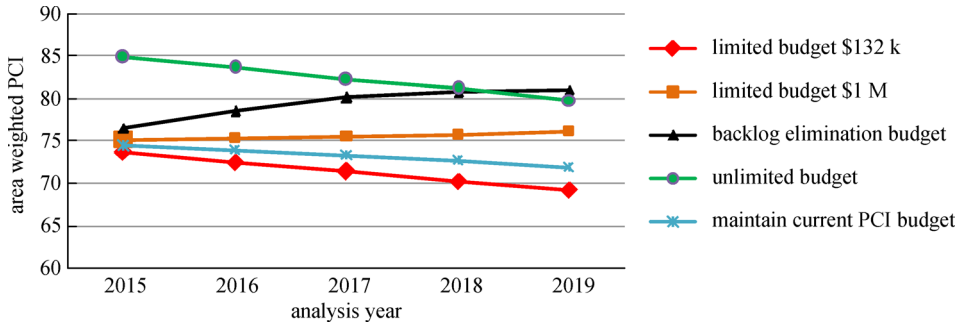

Fig. 5 Comparison of pavement condition for the various budget scenarios

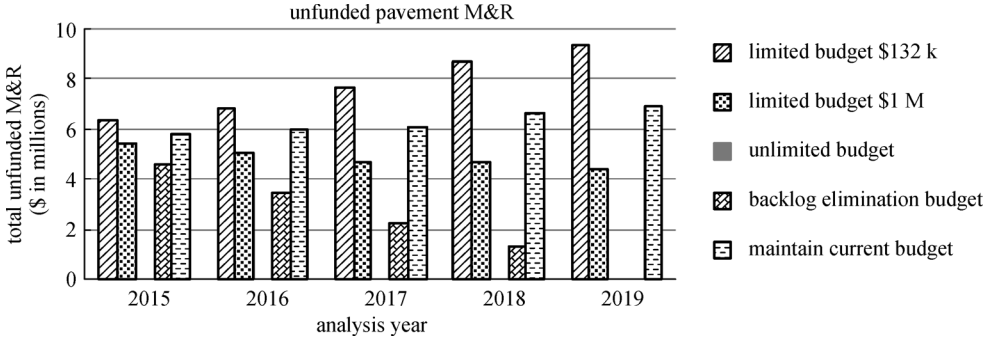

Fig. 6 Effect of budget on total pavement M&R Backlog

Table 10 Summary of budget scenarios analysis in a period of five years

budget scenario	PCI before	PCI after	backlog accumulation
limited budget of $132,000/yr	73.64	69.00	$9 million
limited budget of $1 million/yr	73.64	76.09	$4 million
backlog elimination budget of $1.7 million/yr	73.64	81.09	$0.00
maintaining current PCI budget of $0.6 million	73.64	71.88	$8 million
unlimited budget of $1.5 million/yr	73.64	79.84	$0.00

equal or above critical PCI apply localized or global preventive. If section PCI is bellow critical, apply localized safety and major M&R.

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