SELECTION OF THE MOST COST EFFECTIVE PAVEMENT MAINTENANCE TREATMENT FOR SELECTED AIRPORT PAVEMENTS IN NEW MEXICO

M. RAHMAN & R. TAREFDER
Department of CIVIL Engineering, University of NEW MEXICO, USA
MRAHMAN@UNM.EDU

ABSTRACT

Due to environmental conditions and air traffic, pavements deteriorate with age. Periodic maintenance is of utmost importance to keep them in safe operable condition. Limited studies have been reported on airport pavement maintenance strategies. Cost benefit study of various maintenance alternatives should be analyzed to make the best use of allocated budgets. New Mexico has about 50 general aviation airports with pavement condition varying from serious to good. Most of these airport pavements require immediate maintenance treatment. The current need is to determine the effectiveness of various pavement maintenance strategies for these airfields. In this study, the results of a number of crack treatments (crack sealing, patching) as well as surface treatments (slurry seal, overlay) are compared in terms of Pavement Condition Index (PCI) improvement and resulting service life enhancement. The objective of this study is to select the most cost effective treatment by performing life cycle cost analysis and to select the optimum time for its application. The analysis shows that crack sealing has greater benefit to cost ratio and lower life cycle cost than patching. Also, the critical PCI plays an important role in selecting a cost effective treatment as well as aiming a target level of service.

1. INTRODUCTION

New Mexico has 43 General Aviation (GA) airports with different pavement condition. Fort Sumner Municipal Airport, Grants Milan Municipal Airport, Santa Rosa Municipal Airport and Questa Municipal Airport are four of the New Mexico GA airports with weighted average Pavement Condition Index (PCI) just above the lower limit of critical PCI. Critical PCI is the value of PCI at which the rate of PCI degradation increases with time and the cost of preventive maintenance work increases significantly. It means that if maintenance is not done immediately, the damage will become incredibly expensive to fix. The objective of this study is to select the optimum pavement maintenance strategy for these four airports. The optimum maintenance work is that one which shows the maximum benefit cost ratio. In this current study, benefit values are obtained from PCI improvement or airfield functional condition improvement. Costs are calculated using probabilistic life cycle cost analysis due to different maintenance strategies. Accident cost due to resulting roughness of various maintenance treatments and environmental cost due to air pollution in the time of material production, transportation and application for different maintenance processes are also considered. In order to apply a maintenance work in an airfield, the minimum acceptable PCI has been set equal to the lower value of the critical PCI range.

In this study, decisions have been made using a system dynamic model of different modules developed in Powersim Studio 8. Do nothing PCI deterioration rates at different airports are obtained from a pavement management tool named MicroPAVER which has used the current distress data to develop a trend for each. Money needed to maintain a certain PCI throughout the analysis period, is also estimated using the same tool, which has been used directly to calculate the functional benefit due to various treatments. For probabilistic life cycle cost analysis, a LCC software, RealCost is used. MEPDG has been used to obtain the resulting International Roughness Index (IRI) due to various treatments, which helps determine the accident rates. Environmental damage has been obtained from various hazardous gas emissions due to application of different treatments. Pavement Life Cycle Assessment Tool for Environmental and Economic Effects (PaLATE) is used to determine the air pollution.

2. MOTIVATION AND BACKGROUND

New Mexico Department of Transportation (NMDOT) Aviation Division recently collaborated with Civil Engineering Department of University of New Mexico to perform a survey of the pavements of 43 General Aviation airports of New Mexico for the Federal Aviation Authority (FAA). Their goal was to identify the current condition of runways, taxiways and aprons and propose the necessary preventive maintenances. Creation of a central database including Pavement Condition Index (PCI), predicted PCI, Maintenance and Rehabilitation (M&R) work plan and budget required for different sections of the airport pavement was the key requirement for the decision makers. The current pavement condition of these airports is not good. So selection of the necessary measures to boost the condition of these airport pavements is urgent along with estimating the accompanying financial requirements.

A general aviation airport covers a large range of services, both commercial and non commercial. According to the U.S. Aircraft Owners and Pilots Association, general aviation provides more than one percent of the United States' GDP, accounting for 1.3 million jobs in professional services and manufacturing. Proper allocation of funding for pavement management of those airports is a challenging task. A PCI survey for all New Mexico General Aviation Airports was conducted in 2007. A MicroPAVER database containing detailed pavement distress data and Pavement Condition Index (PCI) data was developed. PCI is a numerical index between 0 and 100 and is a function of pavement distress type, distress severity and distress quantity. It was developed by the U.S. Army Corps of Engineers based on a visual distress survey of the pavement where 100 represents pavement in excellent condition and 0 indicates a pavement in very bad condition. PCI surveying processes and calculation methods have been standardized by ASTM for both roads and airport pavements. PCI decreases with time and traffic. The goal of various pavement maintenance works is to increase the PCI and to reduce the rate of PCI degradation. At the initial age, PCI degradation rate is relatively low but after certain age it goes faster. It is better to apply rehabilitation before a critical PCI (55 to 70) because after that the rehabilitation cost would be 4-5 times higher [1]. Riding comfort or user satisfaction of a pavement is proportional to the square of the PCI. [2]:

$$Riding\ Comfort \propto PCI^2$$ [Where $\propto$ is the symbol of proportionality]

To maintain better functional condition in an airport pavement, Pavement Condition Index should be at least on acceptable limit. To ensure the required PCI, maintenance work should be performed on the airfields periodically. The main purpose of the current study is to compare the functional benefit of different treatments in selected New Mexico airports.

3. OBJECTIVE OF THE STUDY

The objectives of the current study are given in the next page in hierarchical order:

- Using system dynamic model to determine the effectiveness of different pavement maintenance strategies in terms of PCI improvement which indicate better riding comfort for the aircraft passengers. (*Functional Benefit*)
- Determine the most cost effective strategy which will give minimum life cycle treatment cost. (*Economic Benefit*)
- Minimize environmental impacts by evaluating different strategies to determine which will give minimum SO_2, NO_x and particulate matter emission. (*Environmental Benefit*)
- Minimize accident cost which will be obtained from the resulting International Roughness Index (IRI) due to various alternatives. (*Social Benefit*)
- Considering the above benefits and cost for each of the alternatives of the project, select the most optimum treatment which will give the maximum B/C ratio.

4. STUDY APPROACH

The problem addressed in this study is to select the optimum pavement maintenance strategy. This selection has been made based on maximum Benefit to Cost ratio. All the benefits and costs have been converted to monetary terms. Functional benefits have been estimated using PCI increase due to a maintenance treatment which is the key component of this study. Data regarding the life extension of the pavement due to various treatments and their unit costs have been obtained from Airport Cooperative Research Program Synthesis 22: Common Airport Pavement Maintenance Practices [3] and is shown in Table 1. PCI increase data has been obtained from a previous study [2]. For assigning the unit cost of crack sealing, it is assumed to have a typical crack density of 0.25 M/M^2[4]. In calculating total cost, all treatments are applied over the whole area as surface treatment except the spray patching. It is assumed that 50% area should be patched where patching is required.

Table 1 - Unit Cost and Life Extension of Different Maintenance Strategy

Alternative	Maintenance	Unit Cost ($/$M^2$)	Life Extension (Years)	PCI Rise
1	Crack Treatment	1.19-2.38	2-3	5
2	Spray Patching	3.57-9.52	2-5	5
3	Slurry Seal	2.38-4.76	3-7	30
4	Thin Overlay	7.14-10.71	7-12	35

A system dynamic model has been developed using Powersim to estimate the average PCI of different maintenance practices over the analysis period of 20 years. The do nothing PCI trend and the predicted rate of deterioration are determined using MicroPAVER. If a certain PCI is maintained throughout the analysis period of 20 years by applying different types of preventive and major repair in every year of the design life, then the money required to maintain that fixed PCI is estimated using the same tool which is shown is Table 2. In estimating functional benefit it has been assumed that, if a maintenance work in system dynamic model shows a average PCI equal to the PCI maintained by MicroPAVER throughout the life, then it will also give functional benefit equal to the money estimated by MicroPAVER to maintain that certain PCI in 20 years design period. The standard PCI rating scale and a typical pavement do nothing curve with MicroPAVER approach to restore pavement at different PCI are shown in Figure 1.

Table 2 – Pavement Area and Pavement Condition Index of Different Airports

Airport	Pavement Area (M^2)	2012 PCI	2031 PCI	Deterioration Rate (PCI/Year)	PCI Maintained	Money Required ($)
Fort Sumner	150,542	61	29	1.68	77	23,325,225
Grants	84,449	59	26	1.74	84	9,272,285
Santa Rosa	93,638	67	41	1.37	74	13,199,833
Questa	55,860	62	28	1.79	81	7,927,892

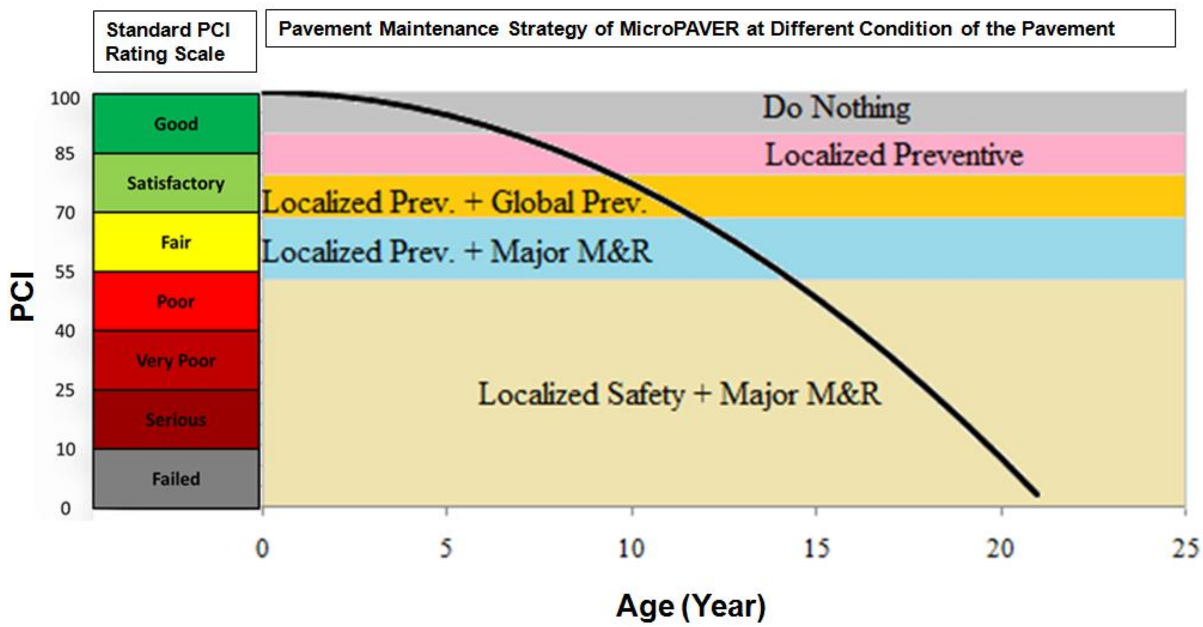

Figure 1 – Standard PCI Rating Scale and Pavement Maintenance Strategy

Functional benefit for different treatments is estimated using the following equation where D is the average do nothing PCI, A is the average PCI in 20 years after applying a treatment alternative which is determined using PCI module developed in Powersim Studio and B is the functional benefit of an alternative. Money needed to maintain a certain PCI M can be obtained from MicroPAVER.

$$B = \$\, needBed\ to\ maintain\ a\ PCI\ M\ throughout\ the\ 20\ years \times \frac{A - D}{M - D}$$

Lower limit of critical PCI is assumed to be the minimum acceptable PCI where 45, 50 and 55 is used for every alternative in the system dynamic model. For a particular treatment alternative, maintenance work has been performed in the base year (2012) and in the year when the PCI approaches the minimum acceptable PCI. Traditionally, the relative difference in benefit due to a rehabilitation is determined by comparing the area under the treatment curve and area under the do nothing curve [5]. To quantifying benefit of a pavement management in monetary terms, a guideline is obtained from previous study [6]. MicroPAVER yields the cost required to maintain a certain PCI throughout the life cycle of the pavement and, using system dynamic model, it is easy to get the average PCI obtained due to a treatment in the design life. If the average PCI is obtained 70 point for a particular treatment from the system dynamic model and 50 is used as a Do Nothing PCI then the PCI improvement due to the treatment is 20. If MicroPAVER recommends $ 1000 to maintain a PCI 80 throughout the entire life of the same airfield using different kind of periodic preventive and major rehabilitation works, then benefit due to the particular treatment will be equal to $ 667 ($1000 \times \frac{20}{80-50}$). Probabilistic life cycle cost analysis has been performed using RealCost to determine the alternative which will give minimum cost in the design period. A system dynamic module is also developed which can be helpful to estimate deterministic life cycle cost (LCC) for different alternatives. RealCost is used to determine the life cycle cost of an alternative and Powersim is used to determine the average PCI obtained due to the life cycle application of the corresponding alternative. It is found that MicroPAVER yields a much higher value of required money comparing life cycle cost of a particular treatment. This is because; MicroPAVER has applied various treatments including localized preventive to major repair work every year in various sections of the airport in order to maintain a constant PCI throughout the analysis period. On the other hand, in this current study, only preventive maintenance treatments are applied but are not applied every year, rather those are applied in the base year and the year when the pavement PCI reaches the minimum acceptable limit. The rehabilitation cost for Pavement Management System (PMS) includes cost of actual work, vehicle operating cost (VOC), cost of user delays, accident cost and cost due to environmental damage [5]. In this current study, VOC and the delay cost are omitted. Accident cost due to traffic hazards and environmental damage cost due to pollution are very difficult to capture. To estimate the environmental damage cost, life cycle gas emission due to different maintenance is calculated using software named Pavement Life Cycle Assessment Tool for Environmental and Economic Effects (PaLATE). PaLATE is developed by University of California, Berkley; and capable of calculating air pollution due to application of various alternatives [7]. Using the volume of the asphalt material needed for different treatments, the vehicular emissions due to transportation and the air pollution due to asphalt production and application processes are obtained. Monetary value or disbenefit of a treatment is used from AEA Technology [8]. Accident costs are calculated using the resulting IRI for different alternatives using MEPDG tool [9]. The most cost effective maintenance treatment is determined by benefit to cost methodology.

5. PROJECT ALTERNATIVES

The following alternatives are considered for the current study. Various crack treatments including

- Crack Sealing
- Spray Patching

Various surface treatments including

- Slurry Seal
- Thin Overlay

Crack sealing is a maintenance technique which seals cracks with rubberized bituminous material. It includes routing of the crack, cleaning the routed surface and applying sealant at the top of the crack. Crack filling is similar to crack sealing, but without the routing. Crack filling is easily damaged by snow plows than and hence is not cost-effective. Spray patching is a maintenance treatment that includes the application of a bituminous compound covered with a layer of aggregate. It can be done manually or by specialized mechanical equipment that sprays an emulsion, applies the cover aggregate, and provides the initial compaction; all in a single pass. If spray patching is applied on the full width of a facility, then it can be considered as a surface treatment. Slurry seal itself is a surface treatment and is an unheated mixture of asphalt emulsion, graded fine aggregate, mineral filler, water, and other additives, mixed and uniformly spread over the pavement surface as slurry. Slurry seal is maintained with the objective of creating a bitumen-rich mortar. Hot mix overlay of AC pavement consists of placing a layer of hot mix over the existing AC surface. Conventional AC overlays are usually constructed with a minimum thickness of $1\frac{1}{2}$ in. Overlays less than $1\frac{1}{2}$ in thick are called thin overlay.

6. ANALYSIS

The key objective of this study, determining the pavement treatment which will give the maximum condition related benefit, has been pursued by developing a system dynamic model in Powersim. To determine the maintenance which will give the minimum life cycle cost has been achieved by probabilistic life cycle cost analysis using a tool named RealCost. Life cycle gas emissions have been estimated using PaLATE. Accident cost is calculated by resulting IRI, MEPDG is used for this purpose. Considering the above parameters for all of the four alternatives, the optimum pavement maintenance strategy is selected according to B/C analysis.

6.1 System Dynamic Modeling

Using Powersim, a system dynamic model has been developed to fulfill the first objective of the project .The model consists of following three modules:

- PCI Module
- Benefit Module
- LCCA Module

The PCI module and the Benefit module have been directly used in making decision or to achieve the first objective. LCCA module is capable of determining deterministic life cycle cost, which is developed just to compare the deterministic results with LCC tool named RealCost. The key inputs required to run the PCI module are initial PCI or the current PCI of the airport pavements (predicted from 2007 survey data), do nothing PCI deterioration rate (predicted by MicroPAVER has shown on Table 2), life extension and PCI rise due to a treatment (Table 1) and minimum acceptable PCI which is assumed to be 45, 50 and 55. PCI is used as the stock and the PCI deterioration rate is used as the flow for this system dynamic model. PCI module can determine PCI in any year of the design life and the average life cycle PCI for different treatment strategies as an output. Figure 2 indicates the PCI module for the slurry seal application in Fort Sumner Municipal Airport where 50 is taken as minimum acceptable PCI. The curve of the top of the figure indicates the do nothing curve or PCI deterioration with time in the analysis period where no maintenance strategy is taken. The life cycle PCI curve means treatment has been applied in the base year and in the years when it reaches the minimum acceptable PCI. In the design period, the application frequency will be the same except the second application as it depends on the initial pavement condition. In this module, PCI rise and the life extension can be varied using the slider bar. Although in this current study fixed values were taken for PCI rise and the life extension for a particular treatment, using this PCI module, further analysis can be performed for other uncertain values also. Stocks and flows are the building blocks of the system dynamic modeling. Stocks are the accumulators of the system; they characterize the state of a system. Flows capture the rate of movement of the commodities; into and out of the system and between stocks. For the PCI module, PCI has been used as stock and the deterioration rate as flow which has shown on the figure with the dirk rectangular box and the circle with a valve respectively. The diamond and the circle represent the constant and the auxiliary respectively. Auxiliary can deal with equations. Time graphs for do-nothing and maintenance PCI are shown in top right of the figure. Benefit can be determined using these two curves.

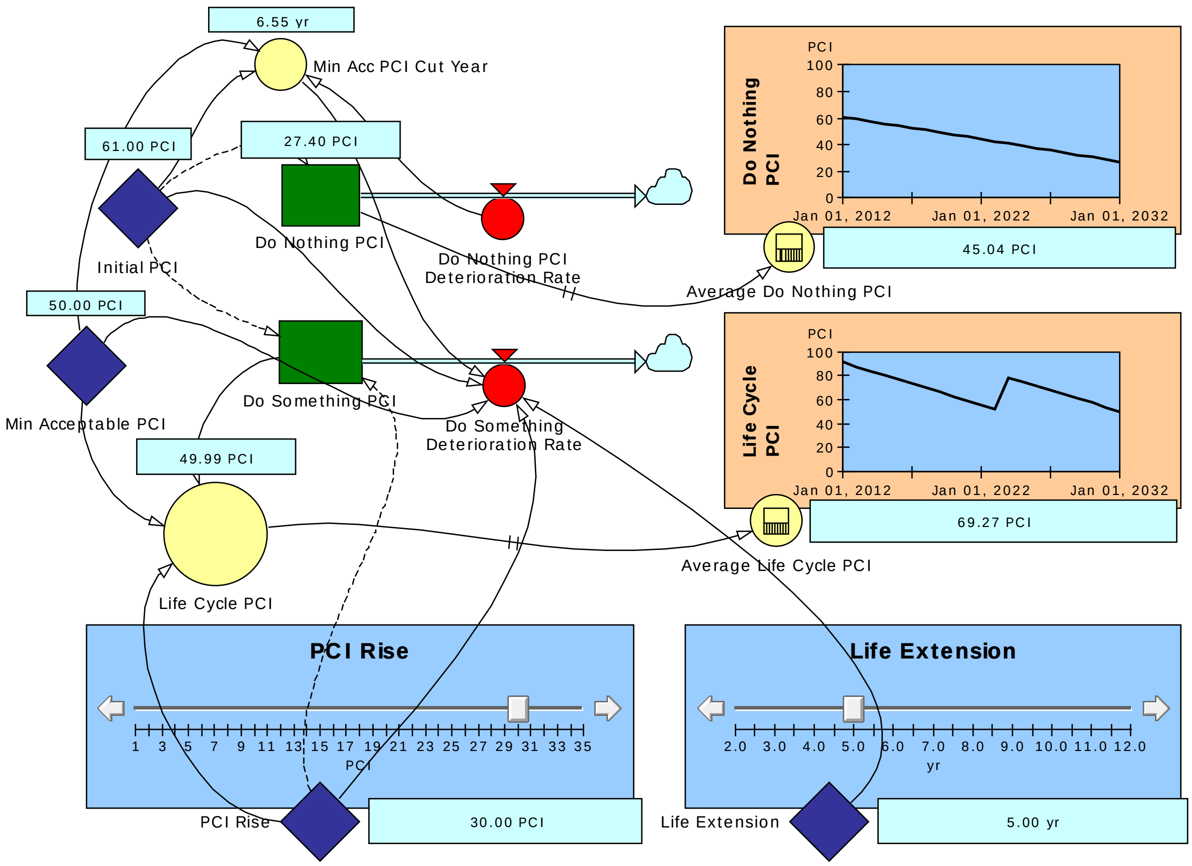

Figure 2 - PCI Module for Slurry Seal in Fort Sumner Municipal Airport

Benefit module has used budget required to maintain a certain PCI throughout the analysis period of 20 years (MicroPAVER), average do nothing PCI and the average life cycle PCI due to a particular work (used from PCI module) as inputs and life cycle benefit as output. Pavement area, unit cost of a treatment, discount rate, design period and frequency of the maintenance treatment are used to calculate life cycle cost in LCCA module. A few assumptions were made, such as: PCI deterioration rate is assumed to be linear but in real case it is parabolic. Except for periodic maintenance, no other yearly maintenance is applied. For life extension in years, the mean value is taken. Life extension is how many extra years a pavement will last due to a treatment and it is the difference between the do nothing and the do something curves where it touches the minimum acceptable PCI. Treatment is applied when PCI reaches the minimum acceptable PCI.

The summary of the results of the system dynamic analysis for Fort Sumner Municipal Airport is shown in Table 3. It indicates that, for a higher value of minimum acceptable PCI for a particular maintenance work, treatment intervals should be lower. As a result the maintenance treatment should be applied more frequently in the analysis period which eventually will cause higher average life cycle PCI and higher functional benefit. As the minimum acceptable PCI was chosen assuming it is equal to the lower limit of critical PCI, the critical PCI plays an important role in functional benefit analysis. But without considering the life cycle cost and benefit to cost ratio, the consequences of different treatments will not be understood properly. For a particular airfield and for a particular minimum acceptable PCI, crack sealing has shown almost the same result of functional benefit to the patching as they improve same PCI point. Thin overlay has shown the highest functional benefit and slurry seal has shown second highest result. The next three airports have given similar trends but are not shown in this paper. As the most significant part of the functional benefit equation is the money required to maintain a certain PCI and this monetary term is higher for larger airfield, Fort Sumner has given the highest benefit and Questa has given the lowest benefit for a particular treatment. Grants and Santa Rosa have also followed this rule. The do nothing PCI and the do something PCI also have little influence on functional benefit. But as the current condition and the PCI deterioration rates are almost same for all four airports, they eventually do not make any difference in decision making. The functional benefit obtained from this analysis has been used directly for the next step of this study.

Table 3 - Functional Benefit of Different Treatments in Fort Sumner Airport

Minimum Acceptable PCI	Maintenance	Avg. Life Cycle PCI	Treatment Interval (Years)	No. of Application in Analysis Period	Functional Benefit ($)
45	Do Nothing	45.04	NA	0	0
	Crack Sealing	52.91	6	4	5,742,210
	Patching	52.93	9	3	5,759,711
	Slurry Seal	68.41	15	2	17,057,100
	Thin Overlay	70.03	21	1	18,239,282
50	Do Nothing	45.04	NA	0	0
	Crack Sealing	55.45	5	5	7,597,484
	Patching	55.37	6	4	7,540,585
	Slurry Seal	69.27	11	2	17,683,749
	Thin Overlay	73.46	18	2	20,742,032
55	Do Nothing	45.04	NA	0	0
	Crack Sealing	58.54	4	6	9,851,357
	Patching	58.72	5	5	9,985,636
	Slurry Seal	73.6	9	3	20,843,818
	Thin Overlay	76.13	12	2	22,689,519

6.2 Life Cycle Cost Analysis

LCCA is an engineering economic analysis tool useful in comparing the relative economic merits of competing construction or rehabilitation design alternatives for a single project. LCCA helps in determining the lowest cost way to accomplish the performance objectives of a project. LCCA is applicable only to decisions where benefits are equal for all alternatives being considered. LCCA process begins with the development of alternatives to fulfill the performance objectives for a project. Initial and future activities involved in implementing each of the project design alternatives are then scheduled and costs of these activities are estimated. For this current study, only direct agency expenditures (maintenance activities) are considered but user costs that result from agency work zone operations is ignored. Using an economic technique known as discounting, these costs have been converted into present dollars and then summed for each alternative. Two computational approaches can be used in LCCA, deterministic and probabilistic. The methods differ in the way they address the variability associated with the LCCA inputs. In the deterministic approach, each LCCA input variable is considered to have a fixed, discrete value. Probabilistic LCCA inputs are defined by probabilistic functions that convey both the range of likely inputs and the likelihood of their occurrence [10]. RealCost 2.5 is used for probabilistic LCCA for this study. In the current study, triangular distribution has been taken to signify the variability of discount rate. For all alternatives 3%, 4% and 5% are chosen as minimum likely, most likely and maximum likely value of the discount rate, respectively. For maintenance cost, normal distribution has been taken. Mean value of unit cost for crack sealing, patching, slurry seal and overlay has taken 1.79, 6.55, 3.57 and 8.93 $\$/M^2$, respectively. Standard deviation for these four alternatives has been obtained 0.6, 2.04, 0.98 and 1.33 $\$/M^2$ respectively. Mean and the standard deviation of each maintenance cost is calculated assuming that if a treatment shows cost of 3.57-9.52 $\$/M^2$ then it has equal probability to cost 3.57, 4.76, 5.95, 7.14, 8.33 and 9.52 $\$/M^2$.

6.2.1 Deterministic Results

Undiscounted expenditure stream at Fort Sumner airport for minimum acceptable PCI 45 has shown in Figure 3. Deterministic results for that airport are presented in Figure 4. 4% is used as a discount rate in this deterministic study. Discount rate is the interest rate by which future costs (in dollars) will be converted to present value. Real discount rates typically range from 3% to 5%. Net present value (NPV) is calculated using following formula, where i is the discount rate and n is the year of maintenance. NPV discounts all the future costs to the present value using a discount factor:

$$NPV = Initial\ cost + \Sigma\ Future\ Cost\ (\frac{1}{(1+i)^n})$$

From Figure 4, it can be said that as a crack treatment, crack sealing is more cost-effective than patching. Slurry seal is a more economical surface treatment than the overlay. The other three airports have shown similar variation in treatment cost for different maintenance treatments. But a decision should not be made without comparing benefit cost results because different alternative have shown different functional benefits which has been discussed previously.

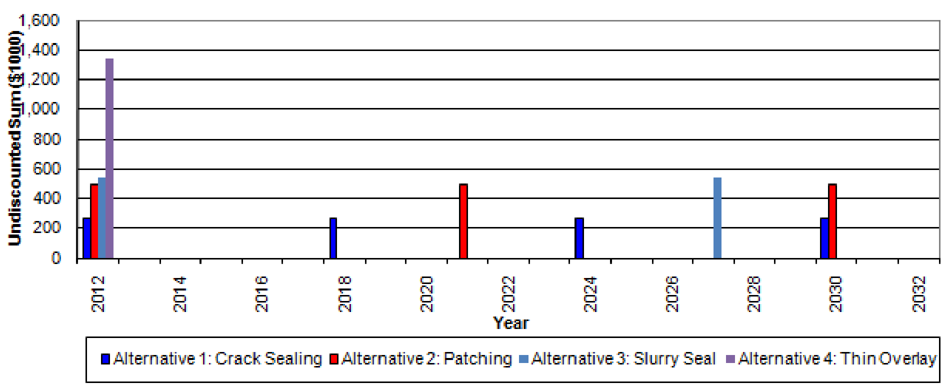

Figure 3 - Expenditure Stream for Minimum Acceptable PCI 45 in Fort Sumner Airport

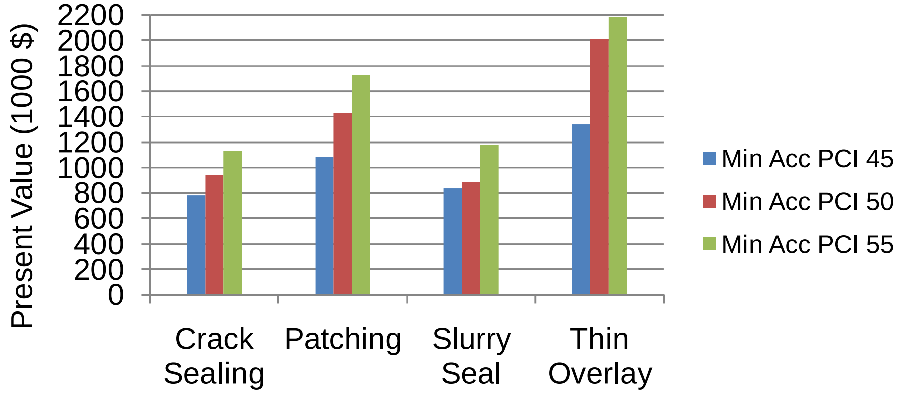

Figure 4 - Deterministic Results of Different Alternatives in Fort Sumner Airport

6.2.2 Probabilistic Results

Probabilistic LCCA is performed using RealCost with 2,000 iterations. Figure 5 shows the risk profile of the NPV for the four alternatives in histogram form for Fort Sumner airport at minimum acceptable PCI 45, where the probability is the area under the curve. The entire ranges of conceivable outcomes are arrayed with the estimated probability of each outcome actually occurring. There is no presumption that any particular alternative is better. The main advantage of the histogram is that it shows the variability about the mean. Wider distribution indicates greater the variability. As shown, the outcome for Alternative 2 (patching) is more uncertain than other alternatives. The cumulative risk profile for maintenance cost in Fort Sumner Airport at minimum acceptable PCI 45 is given in Figure 6. This figure shows the risk profiles for all alternatives in cumulative form. As shown, there is a 40 percent probability that maintenance cost for Alternative 1 (Crack sealing) will be less than $ 750,000. This means that for the 2,000 iterations that were processed, 40 percent of the calculated values for NPV were less than $ 750,000. The variability for the proposed alternative is inversely proportional to the slope of the cumulative curve. In other words, the steeper the slope, the less variability is and the flatter the slope, the greater the variability is. As shown, the slope for Alternative 2 is flatter than that for Alternative 1, and patching is therefore more variable than the crack sealing.

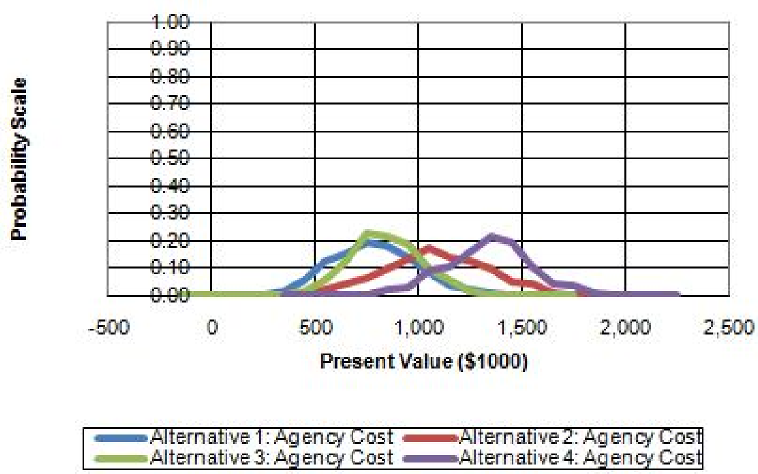

Figure 5 – NPV Histogram for Minimum Acceptable PCI 45 in Fort Sumner Airport

In order to make a decision based on risk analysis results, it is important for the decision maker to define the level of risk the agency can tolerate. Decision makers who can tolerate little risk prefer a small spread in possible results, with most of the probability associated with desirable results. On the other hand, if decision makers are risk-takers, then they will accept a greater amount of spread, or possible variation in the outcome distribution [10]. From Figure 6, clearly Alternative 1 or crack sealing appears to be the better alternative since there is far greater likelihood of cost savings compared to other alternatives. There is 40% probability for Alternative 1 to be less than $750,000 where 40% probability for Alternative 2 to be less than $ 1,000,000.

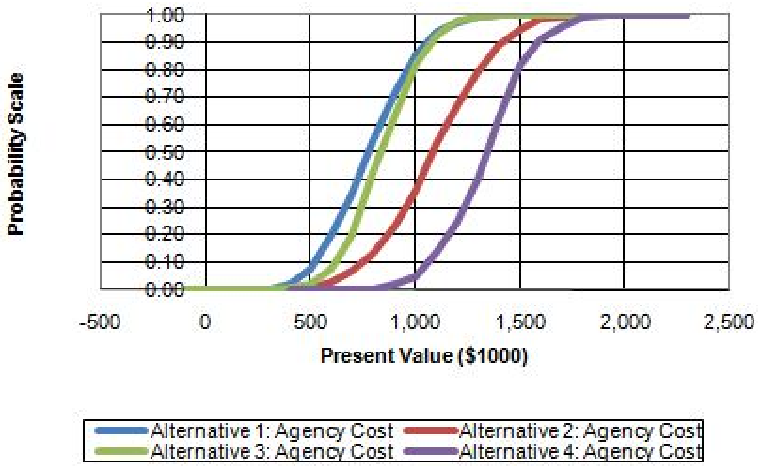

Figure 6 – Cumulative Risk Profile for Minimum Acceptable PCI 45 in Fort Sumner Airport

6.3 Environmental Damage Analysis

Air pollution associated with different maintenance alternatives are calculated using PaLATE. The inputs required to run the analysis for Fort Sumner airport at minimum acceptable PCI 45 are shown in Table 4. The result obtained for the same airport is shown in Table 5. Monetary value of life cycle emission has been obtained from 1806AEA Technology [8]. Using those data, environmental damage cost has been calculated for all the four alternatives. Because of monetary conversion data availability of NO_x, SO_2, and particulate matter, only these three have been considered in the current analysis. In converting previous year dollar value into 2012 value, an escalating factor is used comparing Consumer Price Index (CPI).In PaLATE, initial construction is neglected and default maintenance equipment is used in the analysis. Slurry seal has shown maximum environmental damage cost for Fort Sumner airport at minimum acceptable PCI 45. More amounts of gas emissions have been found from the material production than the material transportation or processes.

Table 4 – Input Chart of PaLATE

Alternative	Area Applied (M^2)	Average Thickness (mm)	Density (ton/m^3)	No of Application	Volume of Work (m^3)
Crack Sealing	150542	3	1.09	4	1806
Patching	75272	6	1.60	3	1354
Slurry Seal	150542	15	1.60	2	4516
Thin Overlay	150542	25	2.38	1	3764

Table 5 – Environmental Cost of Different Treatment in Fort Sumner Airport

Alternative	NO_x (ton)	PM (ton)	SO_2 (ton)	NO_x Cost (2007 USD)	PM Cost (2007 USD)	SO_2 Cost (2007 USD)	Environmental Damage Cost (2012 USD)
Crack Sealing	15.38	2.58	59.96	158306	163415	816895	$ 1,238,814
Patching	11.54	1.92	44.93	118781	121611	612126	$ 927,540
Slurry Seal	38.48	6.43	149.9	396075	407270	2042238	$ 3,095,993
Thin Overlay	32.57	5.44	126.81	335243	344564	1727659	$ 2,619,323

6.4 Accident Cost Analysis

From a typical PCI curve, it is assumed that thin overlay can restore pavement to the same condition as 0-5 years-aged pavement and slurry seal can restore pavement to the same condition as 6-10 years old pavement. After crack treatments, such as patching and crack sealing, pavements behave as though they are 11-15 years old. From New Mexico State Highway 44 Cost Reduction Method, pavement age versus IRI data was obtained [11]. The initial IRI is assumed 1.7 mm/m for crack sealing and patching as an input for MEPDG. For slurry seal and overlay, it is assumed to be 1.25 and 1 mm/m, respectively. Using this data as input, resulting IRI after the end of the first application of crack sealing, patching, slurry seal and overlay was found 2.27, 2.35, 2.09 and 2.02 mm/m, respectively in MEPDG for Fort Sumner airport, which is assumed to be the average IRI of resulting pavement in 20 years period. To run the simulation in MEPDG, traffic input, climate input and the structural input should be given first. Average Annual Daily Truck Traffic (AADTT) is obtained from Equivalent Single Axle Load Factor (ESALF) conversion. The annual operations in Fort Sumner, Grants, Santa Rosa and Questa are 150, 8450, 2130 and 3000 respectively and the heaviest aircraft on their runways is C-III of 42000 lbs. For Fort Sumner the ESALF is found 29.64 or $(\frac{42}{18})^4$. Using an accident versus IRI graph for highway pavement from previous study [9], accidents per 100 million axle pair km is obtained 29, 29, 28 and 28 for the four alternatives respectively for Fort Sumner airport from the Average Annual Daily Traffic (AADT) (0-1000) line. After converting axle load for the corresponding runways, number of accidents in Fort Sumner, Grants, Santa Rosa and Grants airports was found 1, 6, 2 and 2 respectively. It is assumed that one accident consists of one minor injury and one moderate injury only. Then from Economic Values for Federal Aviation Administration (FAA) and Regulatory Decisions [12], Table 6 can be developed for the current airports. As annual operations of General Aviation airports are very low, even converting with the ESALF it has shown very little impacts of IRI on accident rates. As a result of that, same accident numbers were obtained for different treatments in the airfield. For this current study, accidents depend more on annual operation and runway length than on the roughness of the pavement.

Table 6 - Injury Cost for Any Alternative

Airport	No. of Accidents	Accident Cost (2011USD)
Fort Sumner	1	$66,045
Grants	6	$396,270
Santa Rosa	2	$132,090
Questa	2	$132,090

7 BENEFIT COST ANALYSIS

Benefit cost analysis has been performed using the following equation:

$$Cost\ Benefit\ Ratio = \frac{Functional\ Benefit}{Life\ Cycle\ Treatment\ Cost + Emission\ Cost + Accident\ Cost}$$

Although probabilistic life cycle cost analysis has been performed, deterministic LCC values were given as input in the above equation for simplification in the analysis. Figure 7 shows benefit cost ratio for various maintenance treatments applied at different airfields when maintaining different minimum acceptable PCI. For almost all cases, Alternative 3 (slurry seal) has given the maximum B/C ratio among all alternatives. Only for minimum acceptable PCI 45 at Fort Sumner airport and for minimum acceptable PCI 50 at Santa Rosa airport, thin overlay (Alternative 4) has shown better B/C ratio than slurry seal (Alternative 3). If only the crack treatment is considered, then crack sealing has given better result than patching for all airports except Santa Rosa. For Santa Rosa, patching has more B/C ratio than crack sealing, and hence is more effective crack treatment in that airport. It is very important to assign the minimum acceptable PCI in life cycle cost analysis. For Fort Sumner, if minimum acceptable PCI value is taken as 45, then Alternative 4 (thin overlay) shows the best result. But if 50 is taken as the minimum acceptable PCI, then Alternative 3 (slurry seal) shows the highest B/C ratio. As minimum acceptable PCI is assumed from critical PCI, it is important to have a good idea about critical PCI of corresponding airfield.

Figure 7 represents that, each alternative has different benefit to cost ratio at different airfield. Such as, for minimum acceptable PCI 45, slurry seal (Alternative 4) has benefit to cost ratio 3.25 in Questa and 2 in Grants. B/C ratio depends on the condition of the pavement at the time of first maintenance application. The average B/C ratio of all alternatives considering all three minimum acceptable PCI at different pavement condition is shown in Figure 8. Among the four airports, Santa Rosa has the highest current PCI value of 67 and therefore has shown the highest average benefit to cost ratio. Grants has the lowest current PCI and the lowest B/C ratio as well. This analysis can help to select the optimum time for application of a preventive pavement maintenance work. Figure 8 represents that it is better to apply a preventive work when the pavement will be in good condition. It does not mean that, pavements of more good condition will cause more benefit. To draw this type of conclusion, more analysis should be performed considering airports of more varied range of PCI. As different airport are of different size, their pavement area also should be under consideration in benefit to cost analysis.

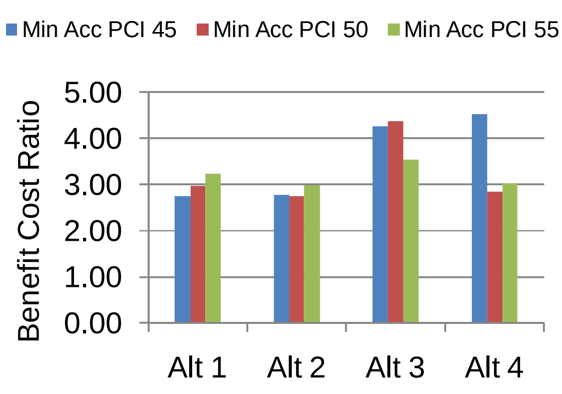

Figure 7(a) - Fort Sumner

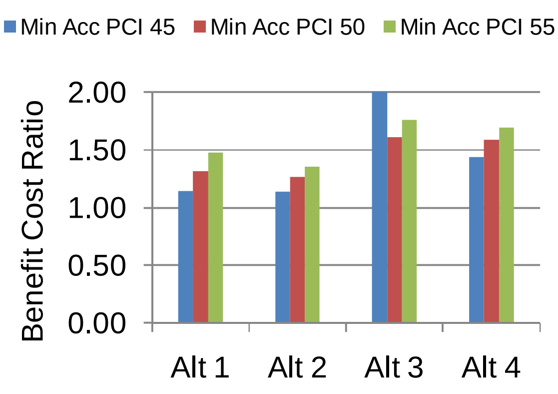

Figure 7(b) - Grants

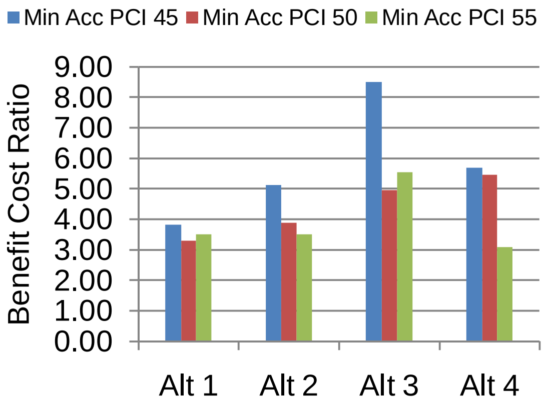

Figure 7(c) - Santa Rosa

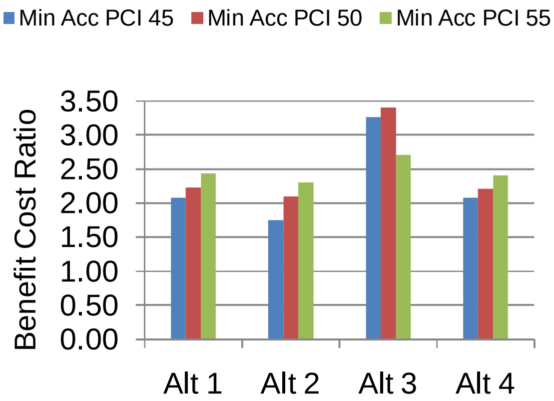

Figure 7(d) - Questa

Figure 7 - Benefit Cost Ratio of Different Alternatives

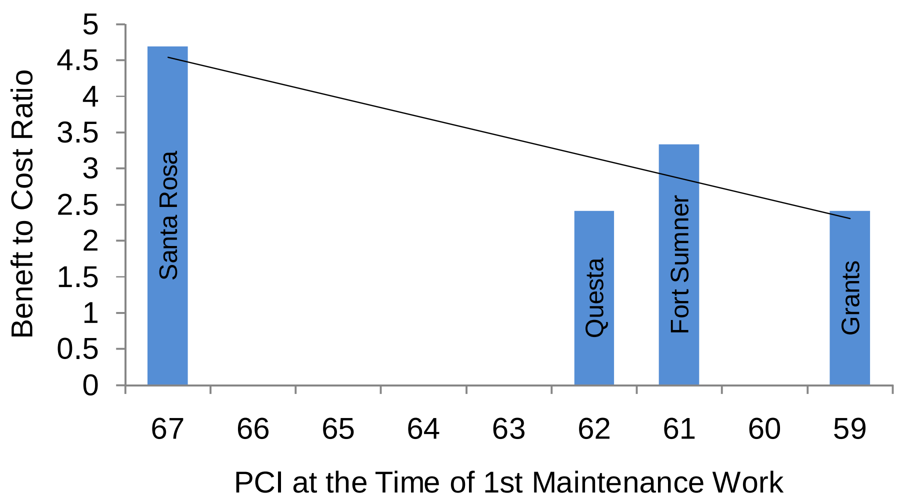

Figure 8 – Average Benefit Cost Ratio at Different Pavement Condition

8 CONCLUSION

Following conclusion can be made based on current study:

- Crack sealing is a better crack treatment than spray patching.
- Critical PCI plays an important role in selecting a cost effective treatment as well as aiming target level of service or assigning minimum acceptable PCI in LCCA.
- Among the four alternatives, slurry seal has the maximum benefit to cost ratio, hence it is the optimum pavement maintenance strategy for this current study.
- As crack sealing is the most cost effective among the four alternatives, if available budget is limited this treatment can be applied on the pavement.
- Thin Overlay has the highest functional benefit..
- Slurry Seal shows maximum emission because it requires more material than the others and, hence, it is more hazardous for the environment.
- It is more effective to apply a preventive maintenance earlier than when it goes close to the lower limit of critical PCI value.

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