

Evaluating Functional and Structural Condition Based Maintenances of Airfield Pavements

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Abstract: This study evaluates airfield pavements' functional- and structural-condition to determine the most economical maintenance method. As a part of the analysis, Pavement Condition Index (PCI) for several runways, taxiways, and aprons has been determined by MicroPAVER. Structural evaluation of airport pavements has been performed by Falling Weight Deflectometer (FWD) test. Evaluation of Layer Moduli and Overlay Design (ELMOD) also determines the required overlay thickness based on the E-values, i.e. FWD data analysis. Damage analysis determines the time of repeated overlay application. In addition, functional parameters have been included to determine the time of functional maintenance. Maintenance and rehabilitation alternatives have been selected to develop different program strategies. Life Cycle Cost Analysis (LCCA) has been performed to determine the maintenance cost. Structural condition based maintenance cost is compared to functional condition based maintenance cost. Comparison shows that structural condition based approach yields cheaper maintenance strategies than functional condition based maintenance approach.

Keywords: Airport and airfield runways, damage, FWD, functional condition, LCCA, pavement management, structural condition.

Introduction

Functional condition evaluation of airfields from visual distress survey data has been practiced for a long time [1,2]. It is a widely accepted method due to its simplicity. It is, however, not the best method. Functional condition is evaluated mainly based on the surface characteristics of a pavement [3]. By using this type of evaluation, it is possible for pavement to be evaluated as in very good condition even though it does not meet the minimum structural condition or standard [4]. Resulting maintenance cost from this evaluation can be much higher than expected. Pavement condition can be accurately evaluated from its structural capacity integrating its surface condition. Thus, maintenance alternatives can be selected based on the actual pavement condition. Excess maintenance cost can be saved significantly. However, the structural condition evaluation process is more expensive and time consuming than functional condition evaluation. Therefore, a study needs to be performed to determine the most economical maintenance method.

This study demonstrates a maintenance methodology that combines structural condition evaluation with functional parameter prediction. This maintenance methodology has been developed for the airfields of nine airports in New Mexico. Each individual airfield maintenance program has been strategized over thirty-five years. Life Cycle Cost Analysis (LCCA) has been performed to determine the required maintenance cost. In addition to this developed maintenance method, functional conditions of the airfields of these same airports have been evaluated from visual distress survey data. A maintenance work plan has been developed over thirty-five years to maintain the expected functional condition. Total maintenance cost estimated from this maintenance work plan has been compared to the structural condition based maintenance to determine the most economical maintenance method.

Objectives

The main goal of this study is to compare airfield maintenance cost based on functional condition evaluation with that based on structural condition evaluation. The most economical maintenance strategy is thus determined from the cost comparison. Specific objectives related to this goal are:

- To evaluate the functional condition of airfields in nine selected airports based on collected distress data using MicroPAVER [5]. In addition, forecasting the functional condition at the end of the selected age of the airfields from the deterioration trend.

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- To estimate functional maintenance cost ensuring the airfields' condition above the threshold value over the program duration.
- To perform overlay design of airfields for the same airports based on the structural evaluation from falling weight deflectometer (FWD) test data. In addition, perform damage analysis to determine the repeated application time of overlay based on operational traffic.
- To develop maintenance strategies integrating functional maintenance alternatives with structural maintenance alternatives.
- To perform LCCA to calculate the total maintenance cost developed using maintenance strategies over selected program periods. Costs are then determined based on the least expensive structural maintenance strategy.
- Finally, to compare functional maintenance cost with structural maintenance cost to determine the most cost effective airfield maintenance strategy.

Method

Visual distress survey data have been accumulated in MicroPAVER to develop a database. Combined functional condition evaluation parameter, Pavement Condition Index (PCI) has been determined for the airfields using the populated distress survey database. PCI value has also been forecasted for selected pavement ages using the deterioration trend. Maintenance alternative requirements have been determined from PCI variation patterns to keep it above the desired minimum level. MicroPAVER determines the maintenance costs for the airfields over program durations of 5, 10, and 35 years.

FWD data, collected from field tests on the selected nine airport pavements have been analyzed by Evaluation of Layer Moduli and Overlay Design (ELMOD) to determine layer strength in terms of E-value, i.e. modulus of elasticity. ELMOD has also performed overlay thickness design using the determined E-values. Integrating overlay thickness and E-values, accumulated damage has been

calculated considering fatigue and permanent deformation in KENLAYER. KENLAYER is a module of pavement analysis and design software, KENPAVE, which is used for flexible pavement [6]. This software was developed in the University of Kentucky. The KENLAYER has a subroutine that can determine the pavement damage using layered elastic analysis. Accumulated damage has been used to determine the repeated time of structural maintenance over the 35 year maintenance plan. In addition, four functional parameters, i.e. rut, International Rough Index (IRI), wear, and friction, have been integrated to include any additional functional maintenance alternative to the strategy. LCCA has been performed to determine the maintenance cost of the developed strategies. These maintenance costs are then normalized to a selected damage value for cost comparison. Cost comparison of normalized maintenance costs yields the most cost effective structural condition based maintenance strategy.

Finally, maintenance cost based on functional condition is compared to structural condition based maintenance cost to find the most cost effective maintenance strategy.

Functional Condition Based Maintenance

Distress Database in MicroPAVER

The visual distress survey for the selected airport pavements from New Mexico has been conducted in 2006-2007 [4]. Collected survey data as well as inventory data for the airport pavements have been given as input to MicroPAVER to develop the database. MicroPAVER calculates PCI using this database. Calculated PCI has been used to evaluate the current condition of airport pavement and predict the future deterioration rate. Work plan for future repair and maintenance has also been strategized using this database. In this database, every airport pavement has been assigned as a network and each network has been divided into several branches. Branches include different runways, taxiways or aprons. Each branch can have

Table 1. Airport Pavement Area and Annual Air Traffic

Network ID	Pavement Area (sq. meter)	Annual Aircraft Operations	Average Annual Growth Rate (%)
Artesia Municipal Airport	351370	11,550	0.20
Cavern City Air Terminal-Carlsbad	457115	9,000	0.70
Fort Sumner Municipal Airport	149849	150	0.50
Grants-Milan Municipal Airport	84060	8,450	0.40
Lea County Regional Airport-Hobbs	464896	11,506	0.60
Lea County Airport-Jal	62120	3,000	0.50
Lordsburg Municipal Airport	50482	4,800	0.40
Questa Municipal Airport Nr 2	55603	300	0.50
Santa Rosa Route 66 Airport	93207	2,130	0.40

one or more sections. The current database contains nine airport networks. Network ID of the airports are Artesia, Carlsbad, Fort Sumner, Grants, Hobbs, Jal, Lordsburg, Questa and Santa Rosa. Table 1 shows the total pavement area and the annual air traffic operation for the nine airports.

Pavement area and annual operations are higher in Artesia, Carlsbad and Hobbs. However, Grants has a very small pavement area with a relatively large number of air traffic.

Functional Condition Evaluation

MicroPAVER calculates the PCI based on the distress data as mentioned earlier. There can be load related distress such as alligator crack, rutting or climate related distress such as longitudinal cracking and bleeding [7]. MicroPAVER is capable of storing distress data of the airport networks as well as determining the condition of each sample unit. It determines PCI based on deduct value calculation for different distresses. For deduct value calculation, it requires distress type, quantity and severity. Deduct value is obtained from the corresponding deduct value curves in ASTM D 5340-04 [8]. Deduct value is the function of density or severity of a distress. PCI is mainly calculated by subtracting the deduct value of all distresses from 100. In fact, PCI ranges from 0 to 100 indicating the worst (0) toward the best (100) condition of pavement.

Current Pavement Condition

Current pavement condition is evaluated by MicroPAVER [5] in terms of PCI. Figures 1 shows the weighted averaged PCI of different runways and airports at the year of distress survey. It is evident that Artesia has the lowest, whereas Santa Rosa has the highest PCI value.

Pavements’ conditions have been classified into seven categories based on PCI values. These are: Failed (0-10), Serious (10-25), Very Poor (25-40), Poor (40-55), Fair (55-70), Satisfactory (70-85), and Good (85-100) [5]. Figures 2(a) and (b) show the number of sections and percent area at different pavement conditions. It has been observed that a total of 59 out of 169 sections are in satisfactory condition. PCI of twenty one

Information from the figures indicates that one third of the pavement area of the whole network is in satisfactory condition. In addition, one third of the area is in fair condition. It has been observed that one percent of the area of the whole network is in failed condition and nine percent of the area is in serious condition. In the network, PCI of twenty one

sections are equal to or below 25. Based on PCI ranking, five runways out of thirty seven are in danger. To get a clear view, PCI contour for Artesia Municipal Airport, as analyzed in MicroPAVER, is shown in Figure 3.

Future Pavement Condition

Functional condition deterioration has been predicted for five and ten years based on current pavement condition [3]. Figure 4 shows the pavement condition of different airports after five, ten, and thirty five years. It is observed that PCI decreases with pavement age. At the year 2046, i.e., 35 years later, PCI falls below 50.

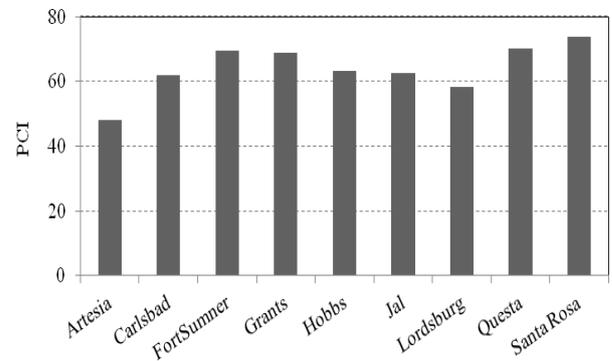
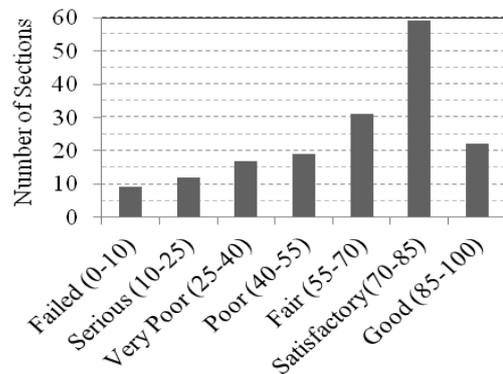
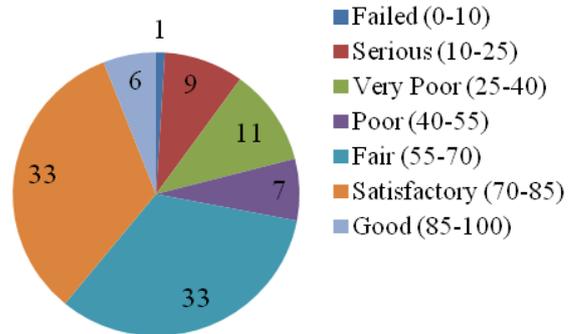


Figure 1. PCI of Runways and Airports



(a) Pavement Conditions of Sections



(b) Pavement Conditions (% Area)

Figure 2. Number of Section and Percent Area of Pavements of Various Conditions

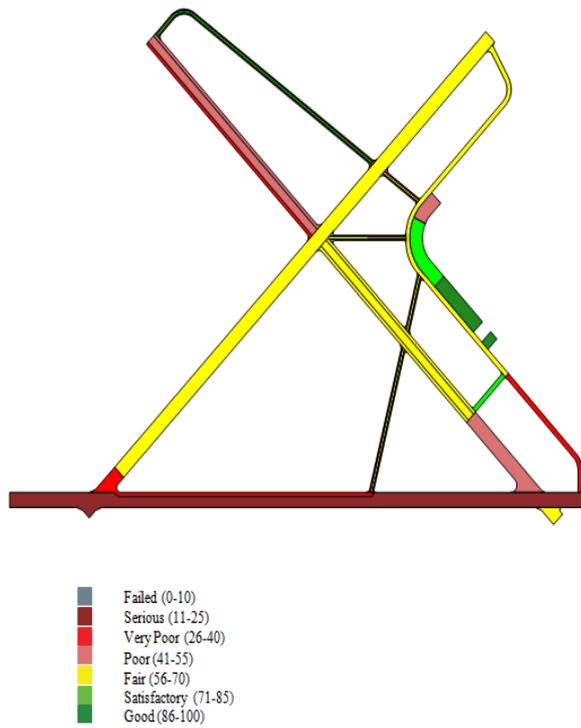
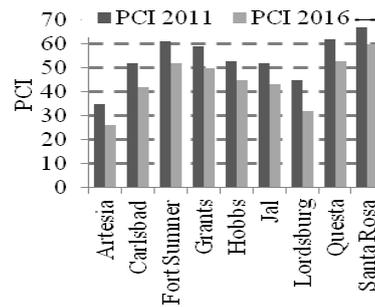


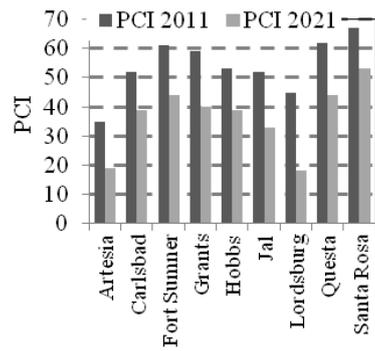
Figure 3. PCI Digital Plan for Artesia Municipal Airport (PCI=69)

Maintenance and Repair Work Plan

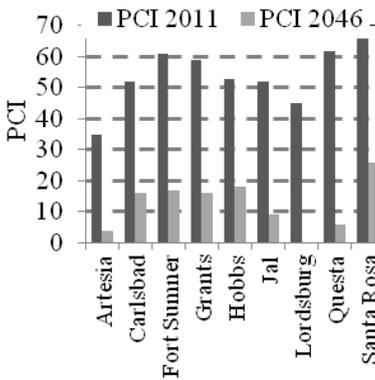
Critical PCI method optimizes Maintenance and Repair (M&R) activity against a specific budget or determines the budget needed to maintain a specific condition level [9]. Five, ten, and thirty five year work plans have been organized in critical PCI method. This work plan has been organized to maintain PCI of 50 ± 3 for the whole pavement area that comprises nine airports. In the five year plan, all airports are maintained in such a way that the weighted averaged PCI of all networks remains about 50 for the next five years. There are four strategies to be used in the work plan. They are localized stopgap, localized preventive, global preventive, and major M&R. Localized stopgap option is used to indicate the use of safety M&R policies that allows MicroPAVER to plan localized stopgap M&R work. For instance, potholes fill on areas where PCI is below critical level. Localized Preventive M&R allows to plan M&R work in localized areas where PCI is above critical. Global Preventive M&R includes any slurry seal or other global preventive work where the pavement life is increased. Major M&R is required where the resulting pavement has a very low PCI. Figure 5 shows five, ten, and thirty five year maintenance costs of maintenance work plans for different runways respectively.



(a) Year: 2016



(b) Year: 2021



(c) Year: 2046

Figure 4. Pavement Conditions Predicted for Five, Ten, and Thirty Five Years

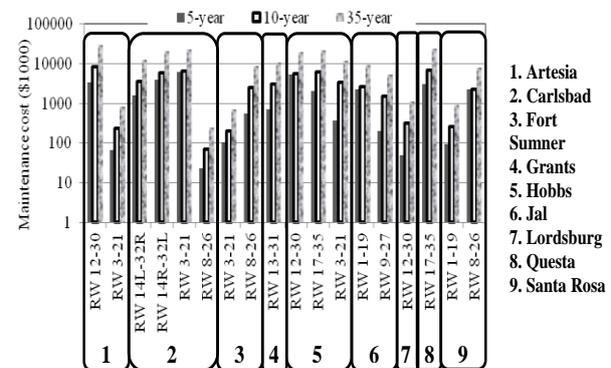


Figure 5. Maintenance Cost of Different Runways

Structural Condition Based Maintenance

FWD Data Collection and Analysis

FWD data collected from the airfields of nine airports have been backcalculated to determine the E-values of pavement layers [10]. ELMOD analyzed these FWD data for three different load magnitudes along the predefined test locations. These backcalculated layer moduli are the representative of strength for each layer in a pavement [11]. These have been used later to determine the required overlay thicknesses as well as damage analysis.

Overlay Design of Airport Pavements

Overlay thickness design needs the serviceable load magnitude and number of repetitions on pavement. However, vehicle load on airport pavements are not the same as those on highways due to the distinct characteristics of gear (or wheel) configuration and operational criteria [12]. The number of aircraft passes on a specific pavement per annum gives the traffic count on airport pavement. This number then needs to be categorized according to operational aircraft types. Thus, it determines the number of load repetition for certain load magnitudes. Based on the available information, the major types of aircrafts in are Skyhawk 172 (Single-engine), Super King Air 350 (Multi-engine), and C130 (Jet-engine). Number of daily operations of each different aircraft is calculated using the following relationship:

$$\text{Daily traffic (specific aircraft)} = \text{Daily traffic} \times \frac{\text{Number of aircraft}}{\text{Total number of aircraft}} \times P \quad (1)$$

where P = percentage of certain aircraft. Air traffic operations in nine airports have been summarized in Table 1, as mentioned earlier.

Table 2. Overlay Thickness of Airfields

Airport	Pavement type	Segment (meter) and Overlay Thickness (mm)							
		0 ~ 304.8	304.8~ 609.6	609.6~ 914.4	914.4~ 1219.2	1219.2~ 1524.0	1524.0~ 1828.8	1828.8~ 2133.6	2133.6~ 2438.4
Artesia Municipal Airport	Runway 3-21	0	0	5	8	5	0	0	
	Runway 12-30	5	5	0	13	5			
	Taxiway B	44							
	Apron	33							
Cavern City Air Terminal-Carlsbad	Runway 8-26	44	40	19	18	20			
	Runway 14L-32R	51	51	51	51				
	Taxiway Charlie	38	51	41					
Grants-Milan Municipal Airport	Runway 13-31	0	11	0	0	0	0	0	8
	Apron	0							
Lea County Regional Airport-Hobbs	Runway 12-30	0	0	0	0	5	0		
	Runway 17-35	51	38	49	18	16			
	Apron	25	41						

A study by Kosasih [13] has shown the method of overlay thickness determination from FWD test data using Asphalt Institute Design Module. This design module was developed based on Asphalt Institute [14]. In this study, ELMOD determines overlay thickness using the back-calculated layer moduli from FWD test data. This software also integrates Asphalt Institute [14] for the overlay design. Calculated overlay thicknesses that are required immediately on the airfields are mentioned in Table 2. It has been seen that the airfields of Artesia Municipal Airport, Cavern City Air Terminal-Carlsbad, Grants-Milan Municipal Airport, and Lea County Regional Airport-Hobbs require the overlay.

Damage Analysis for Overlay Repetition

A pavement, whether it is newly constructed or just maintained with overlay, starts to deteriorate since it is subjected to traffic. Damage due to fatigue or permanent deformation will start to accumulate leading to failure if no further overlay is applied. In addition, surface modulus will also deteriorate with load repetition. Overlay is to be applied repeatedly to maintain the pavement structural condition over a minimum threshold. The time interval for the repetitive overlay application is to be determined for the target damage. It is determined from accumulated damage vs. time variation. Accumulated damage variation with time is developed using the serviceable aircraft operations. Figure 6(a) shows the damage accumulation pattern with time for Artesia Municipal Airport. This pattern follows a nonlinear trend. Three alternatives at different time have been selected maintaining the damage value below the maximum value, i.e. damage value of 1. Figures 6(b) shows the damage variation with time over the maintenance period of 35 years for runway 3-21. The damage variations are plotted for three different alternatives, namely, Alternative 1, Alternative 2,

and Alternative 3. The “Alternative 1” includes the overlay at every ten years interval with the application of slurry seal at every five year interval. The “Alternative 2” includes the overlay at twelve years interval with slurry seal at six years interval. The “Alternative 3” includes the overlay at eleven years interval and slurry seal at five years interval. It shows the accumulated damage value that has been attained just before the time of surface overlay. It is evident that delay in overlay application causes higher damage to pavement.

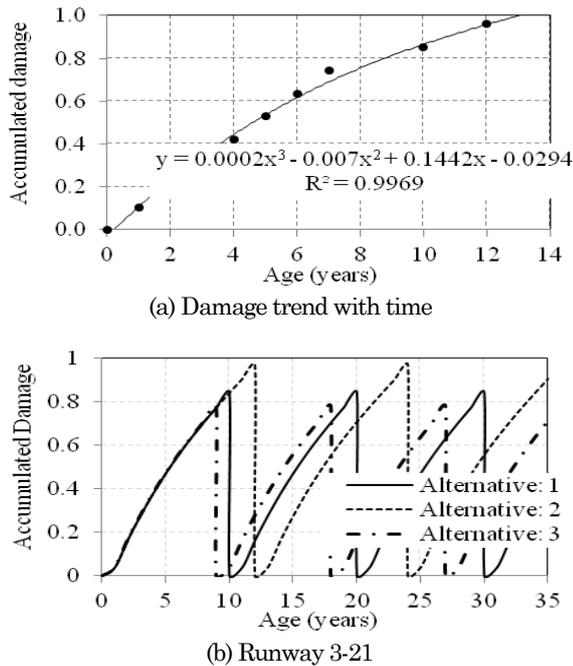


Figure 6. Variation of Accumulated Damage with Time at Artesia Municipal Airport

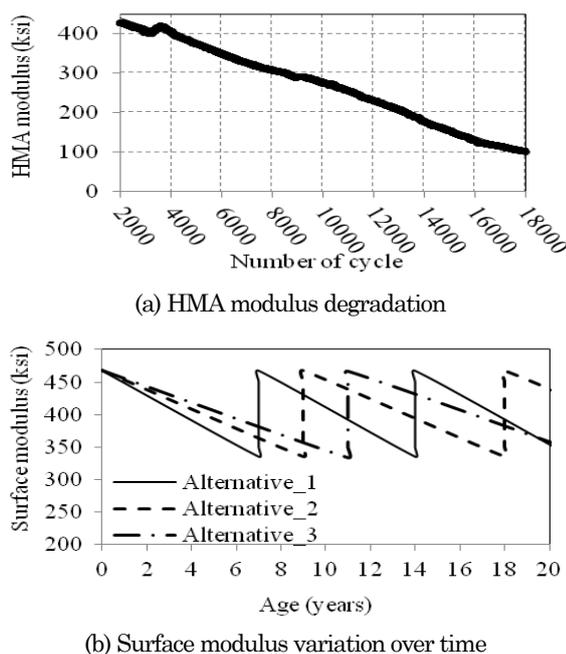


Figure 7. HMA Modulus Variation Over Time

Degraded surface modulus needs to be determined at the time of new overlay design. It has been used for the determination of required overlay thickness. Surface modulus degradation rate is determined from beam fatigue test conducted in the Pavement Engineering Laboratory of Civil Engineering Department, University of New Mexico. Figure 7(a) shows the degradation of HMA modulus with cycle that mimics the load repetition resulting from operational air traffic. Figure 7(b) shows the stream diagram of surface modulus variation over time.

Functional Parameters Degradation

Pavement condition evaluation is performed considering both functional and structural characteristics. Pavement performance is investigated based on functional characteristics for operational traffic distribution. To forecast functional condition deterioration, four different parameters have been selected; they are International Roughness Index (IRI), rut, friction, and wear [12]. These are summarized in Table 3.

Development of Maintenance Alternatives

A section is considered as a critical section whenever the required overlay thickness on that section is the maximum compared to other test sections. This is because overlay is determined based on its combined strength condition contributed by different layers of pavement. From the analysis of overlay design, required overlay thickness has already been determined. Time interval for repetitive overlay application has been calculated using the accumulated damage. Overlay thickness requirement other than the first application is then determined according to repetition, time and degraded surface modulus. Functional parameter variation with time (or traffic) is also integrated to develop the maintenance alternative. To perform a complete life cycle cost analysis, maintenance and rehabilitation alternatives (if any) have been developed over the number of years of the airfield maintenance program. Table 4 shows the airfield maintenance program strategy for the Runway 3-21 in Artesia Municipal Airport.

Maintenance alternatives have been developed combining the structural and functional condition evaluation. This maintenance program has been strategized for 35 years.

Cost Estimation and Comparison of Maintenance Alternatives

LCCA has been performed on the proposed maintenance strategies for the selected airfields [13]. For

Table 3. Model of Functional Condition Parameter Variation

	Model	Parameter
International Roughness Index (IRI)	$IRI = IRI_0 + A \times \left(\frac{N}{10^6}\right)^B$	$IRI = IRI$ at time of concern; $IRI_0 =$ initial IRI
Rutting	$Rut = Rut_0 + A \times \left(\frac{N}{10^6}\right)^B$	$Rut = Rut$ at time of concern; $Rut_0 =$ initial Rut
Friction	$Friction = Friction_0 + A \times \left(\frac{N}{10^6}\right)^B$	$Friction = Friction$ at time of concern; $Friction_0 =$ initial $Friction$
Wear	$Wear = Wear_0 + A \times \left(\frac{N}{10^6}\right)^B$	$Wear = Wear$ at time of concern, $Wear_0 =$ initial $Wear$

N = number of load repetition, i.e. annual departure of traffic; and A, B = arbitrary coefficient assumed by analyst.

Table 4. Maintenance Program Strategy for Artesia Municipal Airport

Artesia Municipal Airport															
RW 3-21															
Year	Alt. 1	Alt. 2	Alt. 3	Year	Alt. 1	Alt. 2	Alt. 3	Year	Alt. 1	Alt. 2	Alt. 3	Year	Alt. 1	Alt. 2	Alt. 3
0	O*	O	O	9		F***		18		S		27			S
1				10	O			19				28			
2				11			O	20	O			29			
3		S**		12		O		21				30	O	S	
4				13				22			O	31			
5	S		S	14				23				32			
6				15	S			24		O		33			O
7				16			S	25	S			34			
8				17				26				35	S		

*O: Overlay **S: Slurry seal ***F: Fog seal

each of the airfields, every strategy has been developed over 35 years as mentioned earlier [14]. These strategies have been compared based on total cost resulting from structural and functional maintenance alternatives. From the maintenance alternatives, it has been observed that overlay is to be implemented at different times during the maintenance period. Thus, accumulated damages just before the applications of overlay at different times are not the same. For the comparison, maintenance costs are normalized as follows:

$$Normalized\ cost\ (\$) = \frac{Total\ maintenance\ cost\ (\$)}{Repeated\ maximum\ damage} \times Damage\ value\ to\ be\ normalized \quad (2)$$

where *Total maintenance cost (\$)* = LCCA determines the cost over 35-year maintenance program, *Repeated maximum damage* = Maximum damage value that is determined from damage variation with time, and *Damage value to be normalized* = Damage value of 0.8 has been selected for normalization. Cost comparisons for other airports are shown in Figure 8. It has been observed that Alternative 2 is the most economical for Artesia Municipal Airport. Comparison also shows that maintenance Alternative 2 is the most economic for Carlsbad Cavern Air Terminal, Grants-Milan

Airport, Lea County-Hobbs, and Artesia Municipal Airport. Alternative 1 is the most economical for Fort Sumner Airport, Lea County-Jal, Lordsburg Airport, Questa Airport, and Santa Rosa Airport based on normalized maintenance cost.

Comparison of Functional and Structural Maintenance

Structural condition based LCCA has been compared with functional condition based cost analysis. These analyses have been performed for the runways of nine airports. Figures 9(a) through (c) show the cost comparison between functional and structural maintenance strategies. These comparisons have been performed for five, ten, and 35 years respectively.

Figure 9(a) shows that functional condition based maintenance cost is greater than structural condition based maintenance cost for twelve runways whereas structural maintenance cost is greater than functional maintenance cost for six runways. Figure 9(b) is plotted to show the cost comparison for ten years of the maintenance program. Similar to the five-year maintenance program, the functional maintenance cost is higher for thirteen runways whereas structural maintenance cost is higher for the other five

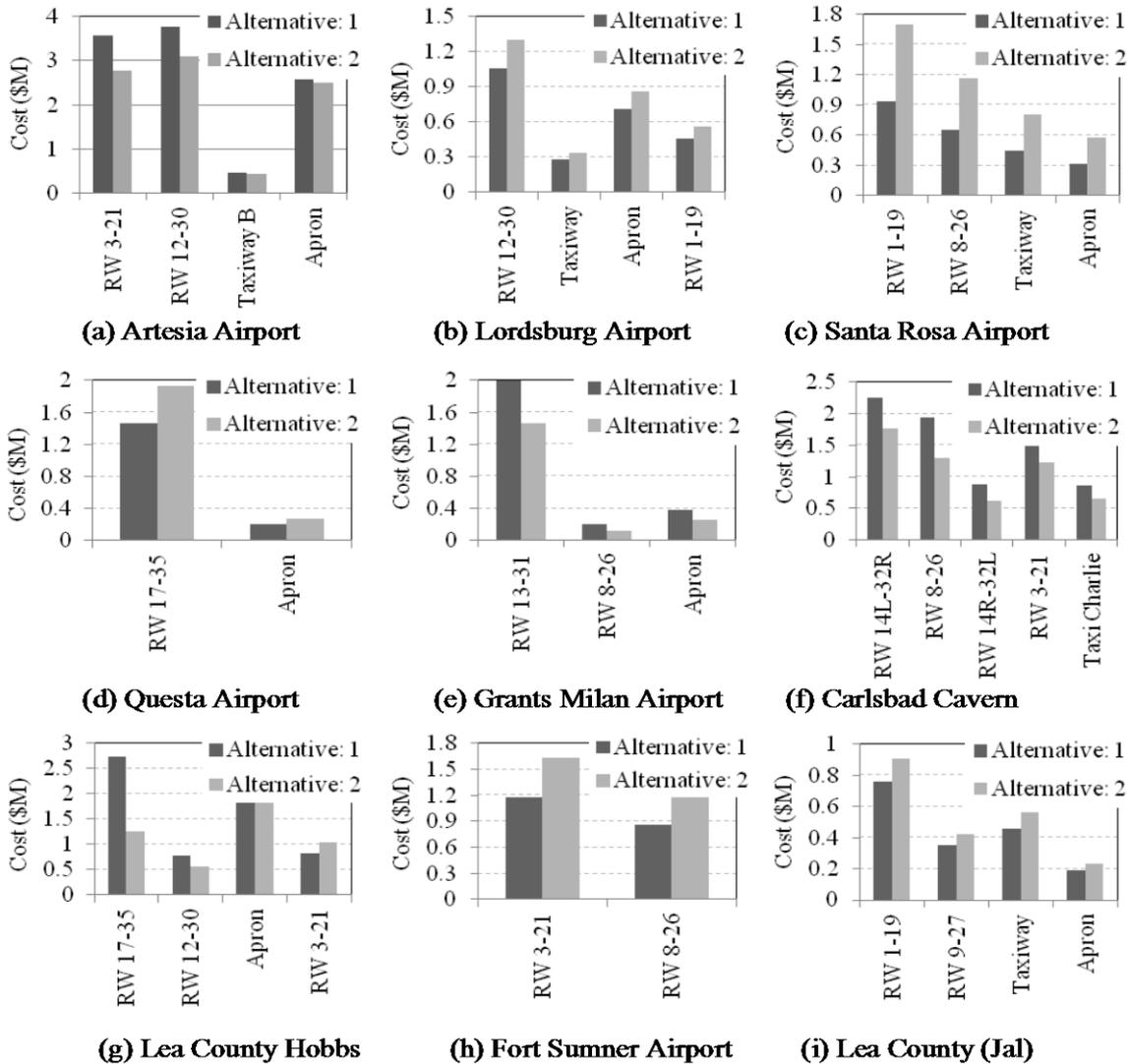


Figure 8. Normalized Cost Comparison of Maintenance Strategies of Airport Pavements

runways. Figure 9(c) shows the maintenance cost comparison for 35 years of the program. For thirteen runways, structural maintenance cost is less than functional maintenance cost. On the contrary, functional maintenance cost is less than structural maintenance cost. It is evident that structural condition based maintenance cost is the most economical based on cost comparison for the selected runways.

Conclusions

Functional condition of the airfields of selected nine airports in New Mexico has been evaluated by MicroPAVER. Maintenance alternatives have been developed based on this evaluation. MicroPAVER estimates the total cost of the developed maintenance strategies. In addition to functional condition evaluation, all the airfields have been evaluated based on structural condition. Different

maintenance strategies for these airfields have been developed according to this evaluation. LCCA has been performed to estimate the total maintenance cost. Both functional and structural condition based maintenance costs have been determined for five, ten, and 35 years. Cost comparison has been performed to figure the most economical maintenance strategies for the airfields. The following conclusions have been drawn from this study:

- Functional condition based maintenance strategy has been developed to maintain a minimum PCI of 50 over pavement serviceable life. It leads to frequent application of maintenance on airfields. Thus, it becomes expensive.
- Structural condition based maintenance strategy mainly addresses pavement strength and remaining life. In addition, it integrates minimal requirement of functional maintenance. Therefore, total cost of this strategy is less expensive.

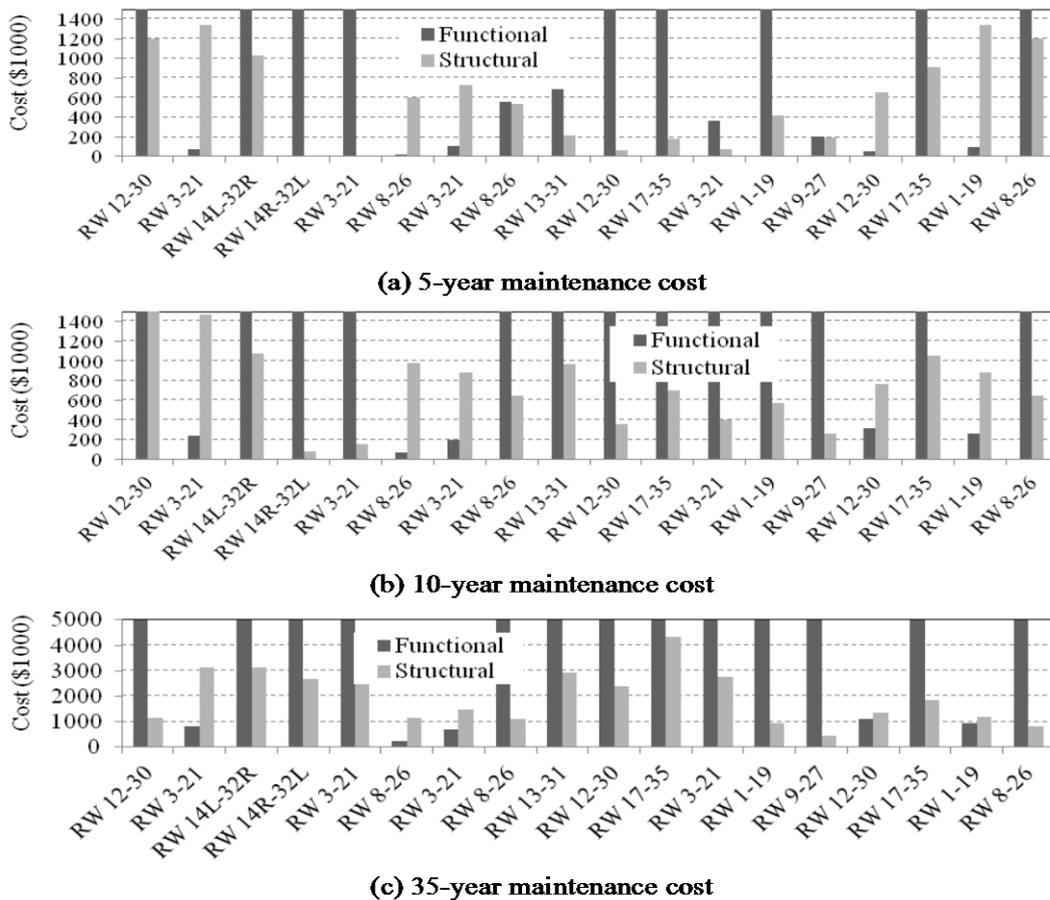


Figure 9. Cost Comparison between Structural and Functional Maintenance

- Functional condition based maintenance has been developed on visual distress survey. A visual distress survey does not guarantee the accuracy of pavement condition prediction. Thus, it may result in higher maintenance cost than required.
- Cost comparison of most of the airfields shows that structural condition based maintenance is the most economical among the two demonstrated methods.

Acknowledgments

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