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RECOMMENDED SELECTIVE MAINTENANCE AND REHABILITATION TREATMENT APPROACH FOR AIR FORCE PRIMARY RIGID RUNWAY PAVEMENT SYSTEMS

THESIS

Christopher M. Twigg, First Lieutenant, USAF

AFIT-ENV-MS-17-M-232

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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THESIS

Presented to the Faculty

Department of Systems and Engineering Management

Graduate School of Engineering and Management

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Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Engineering Management

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First Lieutenant, USAF

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Abstract

The Air Force is facing the challenge to preserve the current inventory of 154 million square yards of paved airfield assets while at the same time reducing the budget by $36.2 billion between fiscal years 2015-2019. This research sought to determine a selective maintenance and rehabilitation treatment approach that allocates resources efficiently to preserve the degrading pavement assets in the financially constrained environment. Air Force pavement inspection reports from the past five years provided 4289 observed pavement distress data points for this research. The data was inputted into the pavement management software, PAVER™, to calculate the Pavement Condition Index (PCI) deduct values for every pavement distress combinations. A pavement distress prioritization list was created from the 111 PCI deduct value calculations to rank the impact that different distresses have on the condition of pavement systems. Finally, the analysis led to a recommended selective maintenance and rehabilitation approach to repair and preserve the most distressed rigid pavement slabs given the constrained resources. The recommendations include treating all medium and high severity joint seal damage with joint seal repair, repairing all pavement slabs with slab replacement that had a PCI less than 70 and with a PCI deduct greater than 10, and using all remaining resources on the Air Force recommended treatments. The recommended approach minimizes the potential of Foreign Object Damage, uses corrective measures in the form of slab replacement to repair the worst conditioned and highest priority slabs, and reduces further pavement degradation with the Air Force recommended treatments.

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I would like to dedicate this thesis to my wife and my daughter.

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Acknowledgments

I would like to express my deepest appreciation to my wife. I would not be where I am today without your constant love and support. I am so grateful for the encouragement and help that you provided throughout the past year and a half. From the bottom of my heart, thank you. I would like to thank my daughter for constantly reminding me of the important things in life. The opportunity to be your dad has been the greatest gift I could ever receive. I would also like to thank my research advisor for your support and advice throughout this research effort. The thesis process has faced numerous setbacks, your guidance always ensured that I remembered the big picture and that I stayed on the right path. Finally, I would like to thank my thesis committee for the technical insight that you provided during this process. I have immersed myself into the pavement world over the past 18 months and I am truly grateful for the vast amount of knowledge that each of you provided to ensure that I was technically proficient.

Christopher M. Twigg

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Table of Contents

Page

المنارة للاستشارات
www.manaraa.com

المنارة للاستشارات

www.manaraa.com

List of Figures

المنارة للاستشارات

www.manaraa.com

List of Tables

Page

المنارة للاستشارات

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RECOMMENDED SELECTIVE MAINTENANCE AND REHABILIATION TREATMENT APPROACH FOR AIR FORCE PRIMARY RIGID RUNWAY PAVEMENT SYSTEMS

I. Introduction

General Issue

The Department of Defense (DoD) is facing a dilemma of how to meet the ever-changing and rapidly expanding security threats facing our nation, while at the same time being limited by the amount of resources available to meet these challenges. The Budget Control Act of 2011 (BCA) established a financial limit for the DoD and significantly reduced each service's available resources. The BCA set the goal to reduce the DoD's budget by $487 billion over 10 years, with the Air Force being responsible for a reduction of $36.2 billion between FY2015-2019 (DoD, 2014, 2015). The significant budgetary reductions forced strategic tradeoffs between the force's current size and future capabilities to defend the nation against emerging high capability threats (DoD, 2014). The financial setbacks will impact both personnel and the ability to maintain Air Force weapon systems and infrastructure assets.

The proper management of the Air Force's current asset inventory is critical to ensure the preservation of the Air Force's infrastructure assets in a financially constrained environment. Asset management aids in efficient resource allocation and, according to the American Association of State Highway and Transportation Officials (AASHTO), is defined as a "systematic process of maintaining, upgrading, and operating physical assets cost-effectively" (Ding, Sun, & Chen, 2013). Similar to the Air Force's budget

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challenges, when looking at the United States highway pavement systems, the estimated costs to rehabilitate these transportation networks exceed the available monetary resources (Orabi, Asce, & El-Rayes, 2012). The issues facing the United States transportation networks like those facing the Air Force, show the importance of properly managing the current asset inventory. In an ideal environment, asset managers could take a proactive approach to maintain assets at a functional level, but the lack of resources limits this approach, thereby forcing the decision-makers to delay the needed maintenance and repair of degraded assets (Wade, Wolters, Peshkin, & Broten, 2001).

Asset management includes adequate and timely maintenance and rehabilitation (M&R) treatment to ensure the pavement system performs throughout the entirety of the design life. Assets should be managed with respect to their designed performance; it is considered satisfactory if an asset performs as designed over its entire useful life (Uddin, Hudson, Haas, 2013). As assets age, the relative condition deteriorates due to numerous factors. In regards to pavement systems, the factors that impact the degradation rate of the pavement include the traffic loading, environment, quality of construction, maintenance, and the structure of the system (Haas, Ralph, & Norman, 2001). These factors lead to a variety of pavement distresses, which impact the structural integrity of the pavement system, shorten the useful life of the asset, and prompt safety concerns due to the creation of foreign object debris (FOD). The presence of FOD directly impacts critical mission operations and presents safety concerns to weapon system operators. The asset cannot provide adequate service when the pavement is structurally unsafe, is functionally obsolete, causes delays and inconvenience to the users, is costly to maintain

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and preserve, or there is catastrophic failure from natural disasters (Uddin, Hudson, & Haas, 2013). For these reasons, asset managers should prioritize pavement systems to ensure that the worst conditioned pavement assets receive the corrective treatment to preserve the life of the pavement and enable the safe execution of mission operations.

The Air Force uses the Pavement Condition Index (PCI) to characterize the surface condition of pavement assets. The PCI is "a numerical rating of the pavement condition that ranges from 0 to 100, with 0 being the worst condition and 100 being the best possible condition" (ASTM D5340-11, 2011). The Army Corps of Engineers developed the PCI rating scale to determine the conditions of different pavement systems, thus making it valuable for managing pavement assets. The PCI provides "a measure of the present condition of the pavement based on the distress observed on the surface of the pavement, which also indicates the structural integrity and surface operational condition" (ASTM D5340-11, 2011; ASTM D6433 07, 2007). Pavement distresses are used to calculate a PCI deduct value, which reduces the pavement's PCI score. PCI deduct values are determined using observational inspections to record three input factors: type of distress, quantity of the distress, and severity of the distress for different pavement sections (Colorado State University, n.d.). The PCI deduct value, for each distress type, increases as the density and severity of the pavement distress increases. The density and severity of pavement distresses worsen if the aging pavement system is left untreated or decision-makers opt for a preservative treatment method instead of required corrective measures. Therefore, asset managers need the tools for efficient resource allocation to correct the pavement distresses that impact the condition of pavement assets. The asset

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management tools provide decision-makers the information about pavement condition, overall cost, and recommended treatment for the pavement system.

The current condition of the pavement system communicates to decision-makers the priority of pavement systems that require treatment. Key condition metrics include observed pavement distress PCI deduct values, FOD index values, and PCI values. A large PCI deduct value lowers the overall condition of the pavement and reduces the structural integrity of the system. A high FOD index value presents safety risks for weapon system operators and leads to mission operation down-time. Finally, a PCI value below the critical limit of 70 has a faster pavement deterioration rate, which shortens the useful life of the asset. Figure 1 illustrates how a pavement deteriorates over time and shows the impact that a PCI value below the critical limit of 70 has on the deterioration rate. The Y-axis represents pavement condition and the X-axis represents time. Asset managers must ensure the pavement condition stays above the critical PCI value, where pavement deterioration increases rapidly, through rehabilitation, maintenance, or repair efforts.

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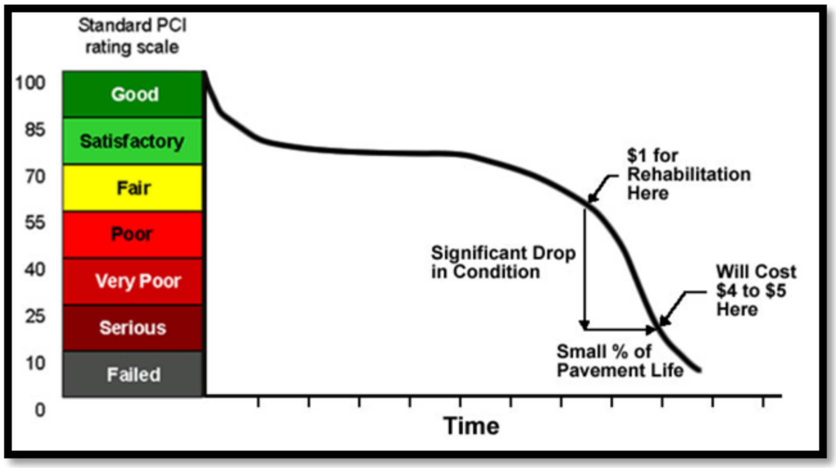

Figure 1: Pavement Condition Index with Respect to Time (CSU, n.d.)

The Air Force needs to preserve the current pavement inventory to ensure safe mission operations. The budgetary constraints, created by the Budget Control Act, enhance the need to manage the current pavement inventory. New department goals, in response to Executive Order 13514, have led to a change in the monetary-conscious culture. These goals, for example "20/20 by 2020," aim at maximizing the effort used to understand the lasting monetary impacts that new assets have on the budget (Executive Order 13514, 2009). Additionally, Air Force Civil Engineers identified "Building Sustainable Installations" as one of three goals in the 2011 U.S. Air Force Civil Engineer Strategic Plan (Meihaus, 2013). Air Force decision-makers must allocate resources efficiently to maintain the current airfield pavement inventory to accomplish this goal.

Asset managers rely on pavement management systems to extend the service life of pavement assets and improve sustainability. For instance, the Army Corps of Engineers established PAVER™ to assist the DoD with managing their vast pavement

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inventory (Colorado State University, n.d.); PAVER™ inventories the pavement condition, work history, and projected PCI values for various pavement systems. The Air Force uses PAVER™ to record and observe deterioration trends and distresses of pavement systems. With the help of asset management systems, like PAVER™, proper M&R work plans can be implemented to optimize the resources allocated to maintain the condition of the current pavement inventory.

Problem Statement

The Air Force's mission statement is to "fly, fight and win in air, space and cyberspace." The Air Force needs to maintain a functional and operational pavement system to ensure mission satisfaction. Currently, the Air Force has a pavement inventory encompassing 154 million square yards of paved airfield (AFCEC, 2013). The need to properly maintain the large pavement inventory in the most optimal manner cannot be emphasized more, due to the critical mission requirements and reduced personnel to maintain these pavement systems. This research analyzed how selective slab replacement aids in the preservation of the Air Force's primary rigid runway pavement systems, even in a financially constrained environment.

An abundant amount of past research analyzed how different M&R treatments impact the condition of pavement systems. Despite the past research, the question of, "How do different funding strategies impact the amount of selective maintenance and rehabilitation treatment that can be used to preserve the condition of Air Force primary runway pavements?", is still left unsupported. The answer to this question would greatly

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help Air Force asset managers make key monetary decisions. The Air Force has different weapon systems, financial constraints, and mission priorities that all shape the asset management decisions. The research aims to develop a recommended treatment approach for the efficient allocation of pavement preservation resources. The approach to only allocate resources on runway sections that need repairs might preserve the runway systems, while successfully meeting budgetary constraints.

A review of literature and research created a foundation for the knowledge required for this research and highlighted any potential research gaps in the literature. The literature review was divided into four sections: asset management, pavement management systems, maintenance and repair, and life cycle cost analysis. First, literature about asset management provided insight of how asset management impacts financial decisions with respect to pavement preservation treatments. Assets need to be managed and preserved in the most optimal manner due to the financial constrains facing the DoD. The second section of the literature review focused on asset management systems. The research addressed asset management systems, like PAVER™, due to the significant implications that these tools have on the condition of Air Force airfield pavement systems. The third section highlights different M&R treatments for rigid pavement systems. The M&R review developed an understanding of past research conducted on each M&R method.

Literature review for M&R techniques, such as selective slab replacement, developed a funding approach that can be applied to Air Force M&R funding strategies. The M&R literature section also looked into pavement deterioration. Literature on

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pavement deterioration provided an in-depth review of how different factors individually impact the deterioration of pavement systems. The research provides an overview on governing standards for pavement systems to determine the current guidelines and how they impact how pavements are repaired and deteriorate for this research. New pavement systems and M&R projects must follow the Unified Facilities Criteria (UFC), American Society for Testing and Materials (ASTM), and Air Force Instruction (AFI) standards. The standards provided the information needed to determine how different distresses impact the condition of rigid airfield pavements. A PCI deduct value is assigned for each distress type, severity and density combination. The standards show how these deduct values are assigned and which combination leads to the largest impact on pavement systems. The final section in the literature review dealt with life-cycle cost analysis (LCCA). Initial costs are currently the primary focus with new projects. The initial cost affects the current budget but neglects to factor in the operations and maintenance costs associated with these assets in future years. The literature review on life-cycle costs was included due to the significant impact that the operations and maintenance costs of aging assets have on the Air Force's budget.

Research Objectives

The goal of this research is to answer the question: How do different funding strategies impact the amount of selective maintenance and rehabilitation treatment that can be used to preserve the condition of Air Force primary runway pavements? To

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accomplish this research objective, the research addresses three sub-questions. The research questions include:

1. How do different pavement distress types, densities, and severities impact the condition of rigid pavement assets?
2. How do different funding environments affect the amount of selective slab replacement on Air Force's primary rigid runway pavement systems?
3. What is the recommended selective maintenance and rehabilitation treatment approach to preserve the Air Force's primary rigid runway pavement systems?

Methodology

The methodology was divided into three major sections. The first section deals with the establishment of a pavement distress priority list. Pavement inspection reports from each Air Force base provided the data to determine the type, density, and severity of all the distresses found on primary Portland Cement Concrete (PCC) runway pavements across the Air Force. Next, the research developed a prioritization system for the preservation of runway sections. An analysis of pavement inspection data and PCI deduction values for each distress type, severity, and density combination led to the determination of which pavement sections should receive slab replacement treatment. The second section created different funding strategies for pavement preservation projects. Past funded projects highlighted the projects that dealt specifically with the sustainment of runway pavements across the Air Force. The amount of resources allocated to these pavement sustainment projects created the three different funding levels: High, Medium and Low. The final section applied the funding levels to actual Air

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Force pavement sections, with the goal to conclude how different funding levels impact the rate of pavement preservation for runway sections.

Chapter Preview

Chapter II looks into past literature and research on pavement condition, maintenance and rehabilitation, loading conditions, and the standards for pavement systems to provide a foundation and discuss any research gaps in the literature. Chapter III outlines the methodology used to gather the needed pavement condition data and how this data was analyzed to make a final conclusion. Chapter IV discusses the findings for this research with respect to how different funding strategies impact the preservation of Air Force runway pavements. Lastly, Chapter V concludes how these findings benefit the Air Force and discusses the possible future research topics for follow-on research.

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II. Literature Review

Asset Management

Asset management is the general framework needed to allocate resources in a manner that prevents the current pavement inventory systems from reaching failure. The Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) define asset management as a systematic process of maintaining, upgrading, and operating physical assets cost effectively (Galehouse, Moulthrop, & Hicks, 2003). "The goal of Asset Management is to get the best results and performance from the preservation, improvement, and operation of infrastructure assets with the resources available" (Transportation Department of California, 2013).

Organizations are confronted with countless investment alternatives and decisions. An organization's asset management program should aim to provide a rational decision-making process to the investment alternatives and improve the condition cost effectively (Galehouse et al., 2003). Past research shows that investing in pavement preservation before the pavement begins to deteriorate at a faster rate will significantly reduce future rehabilitation and reconstruction costs (Keenan, 2005). Successful asset management programs ensure assets are maintained at an acceptable service condition. Maintaining assets at a desired condition is essential because the cost needed to improve the condition to a functional level is far greater after the asset has failed.

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A failed pavement system brings forth numerous issues. The pavement system will not be able to support the loads that the system was originally designed to support, the costs increase to provide continuous short-term maintenance to carry out the daily functions, and the failed pavement will present safety concerns with foreign object damage (FOD). FOD debris can be ingested by aircraft engines, damage tires, and destroy the aircraft's exterior shell (Seiler, 1991). FOD debris presents safety concerns to weapon system operators in addition to the potential aircraft damage. Furthermore, FOD debris removal requires resources and manpower on a recurring basis and leads to operational down-time. For airport network management, pavement condition should be based on the roughness, skid resistance, surface distresses, and FOD potential (Haas, 1997; Ritchie, 1987; Shahin, 1982). The safety issues presented by a failed pavement system create the standard for serviceable pavement system. For the Air Force, a serviceable pavement system should be based on how safely the system can function as designed.

Currently, the vast majority of projects are initiated using the worst-first decision-making technique. The worst-first technique allocates the available resources to the assets that are in the worst condition first, hence the name. The technique has numerous downsides though, to include not addressing the future condition, not taking into account the organizational needs, and allocating resources inefficiently. The effect on the whole network is not considered because only the worst segments are repaired and the project timing is not handled wisely (Wang, Zhang, & Machemehl, 2003). To counter the worst-first technique, asset management should consider optimizing resources. True

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optimization answers three questions: Which repair strategy should be used for a given segment? Which segments should be repaired? When should the repairs be accomplished? (Wood, 1994) To answer the three questions, two optimization models can be used: maximize pavement condition within the budget constraints or minimize costs within the constraint of pavement condition requirements (Wang et al., 2003). Optimizing resources may not address the assets in the worst condition first, but optimization takes into account the organizational needs and which repair treatment will produce the best improvement for resources spent.

Pavement Management Systems

AASHTO defines pavement management as “all the activities involved in the planning, design, construction, maintenance, evaluation and rehabilitation of the pavement portion of public works program” (AASHTO, 1993). Pavement management systems (PMS) are tools that organizations use to track and manage pavement systems efficiently. PMS helps decision-makers choose the most cost-effective M&R techniques to maintain pavement assets in a serviceable condition (Irfan et al., 2015). The Air Force uses the PMS PAVER™ to manage the pavement inventory for the service. PAVER™ enhances the decision-maker’s ability to select the M&R method that maximizes the condition improvement within the available resources (Shahin et al., 1985). PAVER™ provides the users with “data storage, project prioritization, inspection scheduling, determination of present and future network condition, determination of maintenance and repair needs, economic analysis, and budget planning” (Shahin, 1982a). Asset managers

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should use the data from PAVER™ to determine the appropriate pavement preservation strategy. A pavement preservation strategy should address early distresses, correct short distressed sections, prevent further deterioration of assets that are due for rehabilitation, or combine both preventive maintenance with rehabilitation strategies (Luhr et al., n.d.).

The PAVER™ database breaks each pavement network into three different groups for analysis purposes (Shahin, 1982a). The groups include branches, sections, and sample units. Branches, the largest group, are an identifiable part of the pavement network that represents a single entity and has a distinct function (ASTM D5340-11, 2011). An example of a pavement branch is an airfield runway. Sections are smaller components of a branch and are defined as "a contiguous pavement area having uniform construction, maintenance, usage history, and condition. A section should also have the same traffic volume and load intensity" (ASTM D5340-11, 2011). The PCI for the section is determined based on the PCI of the inspected sample units within the section (ASTM D5340-11, 2011). The final group is a sample unit, which is the pavement section used for inspection purposes. For PCC pavements, a pavement sample unit is "a subdivision of a pavement section that has a standard range: 20 continuous slabs (+8 slabs if the total number of slabs in the section is not evenly divided by 20, or to accommodate specific field conditions)" (ASTM D5340-11, 2011). The research analyzes the pavement section groups. Sections group structurally identical pavement areas. By analyzing the section group, the pavement condition impact from different pavement types, construction history, and traffic are minimized.

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PAVER™ uses the pavement's PCI to model the chosen pavement group's future condition and deterioration rates. PCI is a numerical index that rates pavement condition on a zero to 100 rating scale (Shahin, 2005). The PCI rating is based on a visual inspection which identifies pavement distresses, distress quantity, and distress severity (Shahin, 2005). A limitation is that PCI cannot measure the structural capacity, skid resistance, or roughness of the pavement system (ASTM D5340-11, 2011). Another limitation of using PCI to analyze pavement condition is the subjective nature of the inspection process (Irfan et al., 2015). The subjective PCI rating scale may lead to different condition rating scores for similar distressed pavement sections (Irfan et al., 2015). To minimize subjectivity, Air Force pavement inspectors use the *PAVER™ Distress Identification Manuals*. The PAVER™ manuals describe each pavement distress type, the levels of severity, and how to record the distress. PCI values are reduced by PCI deduct values from pavement distress type, severity, and density combinations. The PCI deduct values are derived from curves found in ASTM D5340-11. PAVER™ software includes all of the possible pavement distress deduct curves. After the pavement inspection data is loaded into PAVER™, asset managers can calculate the PCI values and PCI deduct values for each section quickly. Another benefit of PAVER™ software is the reduction of visual errors in the calculation of PCI values and PCI deduct scores. Instead of calculating each PCI deduct score from the printed deduct curves, asset managers who use PAVER™ software can calculate all of the PCI values and PCI deduct scores after recording all of the observed pavement distresses into the software.

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Maintenance and Rehabilitation

Maintenance and rehabilitation (M&R) treatments are the primary method to preserve pavement assets effectively. M&R programs are needed in the Air Force's financially constrained environment. With the reduced financial resources in the Air Force, the current pavement assets need to be managed and repaired before the pavement systems fail. After the failure point, the cost to improve the pavement increases significantly. M&R treatments may adjust the pavement condition by reducing the deterioration rate or improving the current pavement condition immediately after treatment (Mannering & Haddock, 2009). The critical PCI value of a pavement section is the point where the deterioration rate significantly increases and return on investment of preventive maintenance (PM) decreases (AFCEC, 2014). The PCI value of 70 is the default critical PCI value for Air Force pavement systems (AFCEC, 2014). A pavement system with a PCI less than 70 has fallen below the critical condition, thus leading to FOD debris creation and safety concerns. Asset managers should implement M&R treatment strategies to correct all distressed pavement systems before the asset falls below the critical condition. Figure 2 shows the costs associated with the repair of PCC airfield pavements in relation to the PCI of the pavement system (AFCEC, 2014). Figure 2 communicates the need to maintain pavement systems above the critical PCI condition to minimize the cost of the repair treatment.

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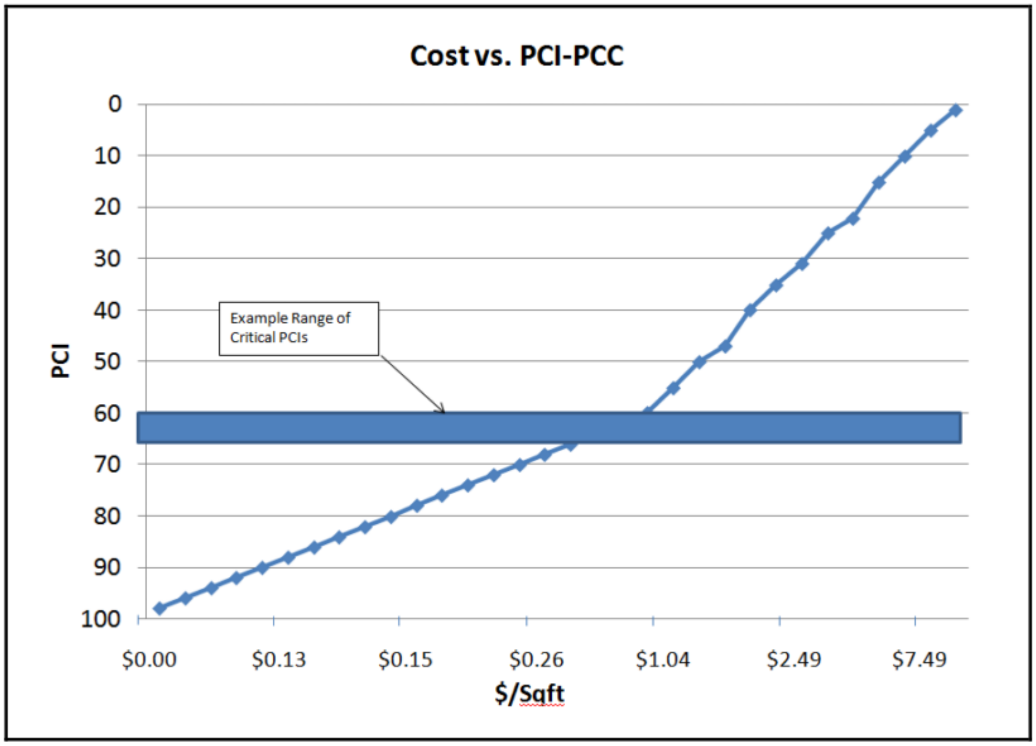

Figure 2: Cost of M&R Treatment vs. PCI-PCC (AFCEC, 2014)

Pavement preservation encompasses all investment methods to slow down the pavement deterioration rate. Pavement preservation is "a system where pavement treatment occurs at an optimum point with the goal of maximizing pavement service life" (Keenan, 2005). Service life is defined as "the period in years over which a building, component, or subsystem provides adequate performance" (Building Research Board, 1991). Additionally, asset performance is "the degree to which a building or other facility serves its users and fulfills the purpose for which it was built or acquired" (Building Research Board, 1991). Two methods are used to improve pavement condition: preventive maintenance and rehabilitation. Common preventive maintenance

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techniques for flexible asphalt pavements include microsurfacing, chip seals, fog seals, crack treatments, slurry seals, mill and fill operations, and hot-mix overlays (Mannering & Haddock, 2009). For rigid pavements, preventive maintenance techniques include load transfer restriction, undersealing, diamond grinding and grooving, and crack or joint sealing (Mannering & Haddock, 2009). Preventive maintenance is a cost-effective strategy for preserving pavement systems and delaying future deterioration. However, preventive maintenance is a short-term solution to slow down deterioration without actually improving the structural condition. In contrast, pavement rehabilitation is a major structural improvement such as resurfacing, partial reconstruction, and complete reconstruction (Wang et al., 2003). The differences between the two pavement preservation methods are their impact on pavement condition. Rehabilitation differs from preventive maintenance by improving the pavement condition, which increases pavement performance (Seiler, 1991). Additionally, M&R treatment methods can be applied on either a local or a global scale. Localized preventive maintenance consists of treatments performed on pavement at the location of the individual distress (AFCEC, 2014). Global preventive maintenance treatments are implemented to slow down the rate of deterioration on a recurring schedule (AFCEC, 2014). The research focused on localized maintenance to repair individual pavement distresses found on Air Force primary rigid runways.

Pavement preservation relies on both the timing and the benefit gained from the M&R (Ding et al., 2013). Technological advances in PMS have made timing the M&R methods easier. However, challenges arise when deciding which M&R technique to

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select. There is no research to prove an optimal M&R method to repair the failing pavement's condition. Numerous factors affect the pavement degradation rate and make a conclusion for the optimal M&R method difficult. There is an inability to link different factors to their exact contribution to the pavement degradation (Luhr et al., n.d.). In addition to the numerous factors, each impacting degradation at a different rate, pavement management databases pose difficulties in understanding M&R effectiveness (Luhr et al., n.d.). Most PMS do not have integrated data from routine or preventive maintenance activities and most historical data has not been statistically designed (Luhr et al., n.d.). Preventive maintenance does not improve the pavement system's condition, but the preventive maintenance techniques aid in decreasing the pavement deterioration rate. Without the proper preventive maintenance work history, PMS cannot adequately predict pavement degradation. Inadequate pavement degradation prediction models impede the decision-maker's ability to utilize the PMS information for resource allocation decisions.

Past research shows that M&R techniques are comprised of four tasks: surface evaluation, analysis and evaluation of structural adequacy, design of alternative strategies, and selection of the optimal strategy (Ismail et al., 2009; Ritchie, 1987). The optimal M&R strategy is based on the largest impact to the pavement condition by targeting pavement slabs with the highest PCI deduct values. Different M&R treatments impact the pavement condition in numerous ways, to include: immediate PCI improvement, a reduction of pavement deterioration, and a reduced FOD potential.

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Life-Cycle Cost Analysis

Life-cycle cost analysis (LCCA) analyzes the total costs for different investment decisions. The analysis includes not only the investment's initial upfront costs, but also the recurring maintenance and rehabilitation costs. The FHWA defines LCCA as "an analysis technique that builds on the well-founded principles of economic analysis to evaluate the over-all-long-term economic efficiency between competing alternative investment options" (Walls & Smith, 1998). The goal of LCCA is "to identify the best value (lowest long-term costs that satisfies the performance objective) for investment expenditures" (Walls & Smith, 1998). Decision-makers need to prioritize projects due to the limited resources available for repair treatments. According to ETL 14-3, "project prioritization requires balancing the cost, mission impact, and risks to create a sustainable airfield over time." Decision-makers focused on the sustainability of the airfield pavement system should maximize the extended service life in relation to the investment resources required.

The longer expected service life of pavement assets has led to an emphasis shift among decision-makers. The shift focuses on M&R treatments compared to the complete construction of a new pavement system (Irfan et al., 2015). The emphasis shift to M&R treatments places a higher importance on accurately conducting an LCCA early in the decision-making process. Proper LCCA faces challenges due to the numerous variables needed for the cost prediction method. The challenges facing LCCA include determining an appropriate discount rate, quantifying user costs, securing credible data, estimating

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salvage value, estimating maintenance costs and effectiveness, and modeling asset deterioration (Guven, Rangaraju, & Amirkhanian, 2008).

Two approaches are justified to calculate an LCCA for an investment option. For an LCCA, decision-makers could select either a deterministic or a probabilistic approach. The two modeling approaches account for the uncertainty found in the input variables (Guven et al., 2008). Uncertainty comes from human input error, lack of credible data, and regional construction variation (Guven et al., 2008). Deterministic modeling treats each input variable as a discrete fixed value. The downside with the deterministic modeling technique is that treating input values as fixed discrete values increases risk by not capturing uncertainty in the model.

The probabilistic approach uses input value ranges and computer simulation to determine investment decision LCCAs (Guven et al., 2008). Input value ranges are a better method to capture uncertainty. The risk associated with the input value uncertainty is minimized with the probabilistic approach through computer-simulated trials. The probabilistic modeling technique uses the probability distribution curve that best fits the simulated data. With a high number of simulated trials, the simulated output value will begin to approach the true LCCA value for the simulated option. The benefits of the probabilistic technique lead to the conclusion “the LCCA system is much more valid and powerful if all the inputs are analyzed probabilistically” (Ozbay et al., 2003).

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Chapter Summary

Chapter II analyzed past literature and studies relevant to the thesis research. The literature topics included asset management, pavement management systems, maintenance and rehabilitation, and life cycle cost analysis. The research team based the research on proper management of Air Force pavement assets. The asset management review provided the foundation required to determine what factors impact proper asset management techniques. In addition, the research team used PAVER™ as the primary database and software tool to gather data and conduct the analysis. A thorough background of the PMS provided the team the knowledge of how to best use the software. Finally, the team conducted a review on M&R techniques and LCCA to gain insight of how M&R treatments impact the condition of the pavement system, initially and over the service life of the asset.

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III. Methodology

Chapter III covers the methodology for the thesis research. The chapter discusses the procedures and analysis techniques taken to answer the three research questions. The methodology was divided into three sections.

1. The process to calculate the impact that different pavement distresses, densities and severities have on the condition of Air Force's primary rigid runway pavement systems.

2. The procedures to create three different funding strategies for the preservation of runway pavement systems.

3. The resources required to maintain the pavement systems at various condition thresholds, compares of the pavement preservation between the funding levels, and develops the recommended funding approach.

Each section builds upon the next, and the three sections focus on the overarching research goal to determine how different funding strategies impact the amount of selective slab replacement that can be used to preserve the condition of Air Force primary rigid runway pavements.

Pavement Distress Impact

The first section covered the steps necessary to calculate the impact of different pavement distresses on the condition of rigid pavement systems. PCC and rigid pavements were used interchangeably throughout the thesis research. PCC and rigid pavements are defined as an "aggregate mixture with portland cement binder including nonreinforced and reinforced jointed pavement" (ASTM D5340-11, 2011). The goal of

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the first phase of the methodology answered which pavement distress, severity, and density combination has the greatest impact on the pavement condition. The outcome of this phase helped develop a prioritization list to determine which pavement slabs should be funded first based on the inspection data. The constrained fiscal environment of the Air Force led to the prioritization need of where to allocate preservation resources. The priority ranking scale, from this phase of the research, developed the prioritization tool needed for smart asset management decisions.

Data Collection

The data was gathered from the PAVER™ pavement management system. The databases for each Continental United States (CONUS) Air Force Base provided the pavement section's pavement condition index, and distresses from the most recent visual inspection. In addition to pavement condition, the databases included the pavement's surface type, traffic condition, total slabs, PCI deduct, surface area, distress type, distress severity, distress density, and rank (Primary, Secondary) for each pavement section on every Air Force Base airfield. The detailed information for every observed pavement distress found across the CONUS Air Force bases, for primary rigid runway systems, was the most important information from the pavement reports. The pavement reports also included distress severity and density data. The severity and density data provided the values necessary to calculate the PCI deduct calculation and priority ranking table. Only primary runway pavement section for each Air Force Base were analyzed due to the large amount of pavement sections for each airfield. Primary pavement systems are mission

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essential pavements used by aircraft on a daily basis (AFCEC, 2014). Primary runways are the focus for this research because of the need to maintain these systems to maintain essential mission operations. Additionally, the analysis only viewed the data for rigid pavement systems. Rigid pavement systems comprise a large portion of the primary runway systems across the Air Force. The focus on rigid pavement systems may limit the applicability of the research findings to only one structural class, but the findings apply to a large portion of critical Air Force pavement systems. Therefore, the reduced research focus to only primary rigid runways may limit the extrapolation of the research, but the conclusions apply to the most critical component of a base's airfield operations.

PCI Deduct Calculations

The next step of the research involved the calculation of pavement deduction values for each distress type, severity, and density combination. There are 16 different distress types found on rigid airfield pavement systems. The possible distresses for rigid airfield pavement systems include: Blowup, Corner Break, Cracks, Durability ("D") Cracking, Joint Seal Damage, Small Patch, Large Patch, Popouts, Pumping, Scaling, Settlement or Faulting, Shattered Slab, Shrinkage Cracks, Spalling (Joint), Spalling (Corner), and Alkali Silica Reaction (US Army Corps of Engineers, 2009). Each distress type impacts the condition of the pavement in a different way; therefore, the research included all 16 distress types in the analysis.

The severity of the observed distress also factors into the PCI deduct value calculation. Severity levels vary based on the distress type, but in general, distress

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severity is defined as “a measure of how badly or to what intensity a given defect has deteriorated” (WDOT, 1992). The severity level impacts the PCI deduct score for all distress types except shrinkage cracking, pumping, and popouts. These three distress type exceptions only factor into the density level for the PCI deduct calculation. Distress severities are recorded as being either a Low, Medium, or High for each distress type, besides the three exceptions. The *PAVER™ Distress Identification Manuals* describe the severity levels, which vary based on the type of the distress. The detailed manual provides an objective inspection approach for the Air Force’s pavement inspections. The standardized scoring method helps to reduce subjectivity in the visual inspection of the PCI inspection.

Density is the final factor that changes the PCI deduct value for each distress. Density is the percent of the pavement branch, section, slab, or sample with the observed distress. For this research, density was defined as the percent of the pavement section with the observed distress. Out of all possible distress types, joint seal damage was the only distress type for which density did not impact the PCI deduct value. Joint seal damage is “counted on a slab-by-slab basis, but is related to the overall condition of the sealant in the sample unit” (ASTM D5340-11, 2011). For joint seal damage, the observed distress is recorded as either present or absent (100 percent or zero percent). For all other distress types, the PCI deduct calculations required discrete density bins due to the continuous nature of density values found in the pavement inspection reports.

Three discrete density bins, for each distress type, were used to calculate the PCI deduct values for each density combination. The three density bins are defined as: Low,

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Medium, and High level of density. The actual pavement distresses, recorded in the pavement inspections across the Air Force, defined the cutoff limits for each bin. Descriptive statistics, from JMP® statistical analysis software, led to the cutoff limits for each density bin. Descriptive statistics outlined the following values for the range of densities for each distress type: count, minimum, first quartile, median, third quartile, and maximum density value. The Low-density bin encompassed all observed density values between the minimum value and the first quartile value; this represents 25 percent of all observed density values across the CONUS Air Force Bases for each distress type. The Medium-density bin included the density values between the first quartile and the third quartile, which accounts for 50 percent of the observed density values. The High-density bin comprised all the density values from the third quartile to the maximum reported density value. The creation of density bins was essential for the calculation of PCI deduct values and reduced the number of PCI deduct calculations from 4289 (for all observed distresses) to only 111 (for every possible distress combination). Additionally, the density bins provide the base decision-makers the tools required to determine the slab replacement priority for their individual base from the inspected density values in a quick and efficient manner.

The distress density values were rounded to the nearest five percent increment for the PCI deduct calculations in PAVER™. Rigid pavement inspections are typically broken into 20 slab samples, with each sample slab representing five percent of the entire pavement section. The density values found in the reports are continuous values because of the large slab quantities found across runway sections in the Air Force. Furthermore,

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the inspection reports use weighted averages for PCI calculations, which leads to exact decimal density values. However, pavement inspectors calculate density by how many whole slabs have the observed distress and not to the exact decimal. Therefore, for real-world application, the PCI deduct values used density bins rounded up to the nearest five percent to represent whole slab values. Rounding the density values may lead to a larger PCI deduct value for certain distresses, but the density bins accurately reflect the density recording process used during actual pavement inspections.

The final step involved the actual PCI deduct value calculation. PAVER™ calculated the PCI deduct value for each distress type, severity, and density combination. Without the use of PAVER™ for the calculations, the deduct curves would be required to determine the PCI deduct value. This process would lead to numerous visual errors, and it is not as exact as the PAVER™ inspection tool, which has the PCI deduct value curves built into the software.

Finally, a prioritization list was created from the PCI deduct values for each pavement distress combination. The prioritization list provides decision-makers a tool that ranks each distress combination by their impact to the pavement system. Additionally, the prioritization list provides a means to visualize which distresses should be corrected first. The prioritization list used the PCI deduct values as the ranking metric instead of other metrics like the FOD index. The prioritization list used the PCI deduct values because of the ease of applicability for decision makers, and how PCI deduct scores encompass the values for the FOD index calculation. The FOD index is a numerical scale from 0-100, where a low value represents a lower presence of FOD

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compared to higher values. The FOD index calculation is simply 100 minus the section PCI value, considering only the FOD creating distresses.

The FOD index only factors in pavement distresses that can lead to the creation of FOD. For rigid runway systems, only three distresses are not considered FOD creating distresses out of the possible 16 pavement distresses. According to AFI 32-1041, only Alkali Silica Reaction, Shrinkage Cracking, and Faulting are not considered in the FOD index calculation (AFCEC, 2013). The PCI deduct calculation takes into account all of the distresses used for the FOD index and an additional three distresses; therefore, the prioritization list only factored in the PCI deduct values.

Funding Strategy

The next research task focused on the funding approach for the preservation of Air Force rigid runway systems. The next phase of the research focused on the goal to create three different funding levels based on past funded pavement projects across the Air Force. The ability to preserve rigid runway pavement systems could be calculated based on the available resources for each subsequent year. The outcome gives decision-makers the data needed to determine what condition was attained based on different funding environments, if the Air Force solely used selective slab replacement to preserve pavement systems.

The first step for creating different funding levels involved a detailed analysis of past funded pavement projects. For this step, construction-tasking orders for Fiscal Year (FY) 2014 -2016 established the amount of resources allocated to pavement sustainment,

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restoration and modernization (SRM). Three fiscal years provided a larger sample size to establish the funding levels. Construction tasking orders display all of the funded projects for each fiscal year. The tasking orders present the following data for each project: Program, MAJCOM, Base, Project Number, Project Title, Integrated Priority List (IPL) Program Amount (PA), Execution Agent, and Time on Target. Only three categories were used to determine the different funding levels, to include: Program, Project Title and IPL PA (Cost). The Program category isolated the funded projects to those that only deal with SRM. In addition, the project title narrowed the projects to those projects that involve runway pavements; this led to the exclusion of pavement projects that only dealt with the preservation of roads, taxiways, aprons, overruns, or shoulders. Finally, the IPL PA (Cost) column of the tasking orders broke out the cost for each individual project for the given FY.

The construction tasking orders narrowed the past funded projects to only SRM projects on runway pavement systems. The sum for all of the project costs were calculated after the exclusion of all of the projects that did not meet the criteria. The sum represented the amount of money obligated to runway preservation for each fiscal year. Each of the three different fiscal year averages occurred during different moments in time. Inflation values, from the Bureau of Labor Statistics, brought every fiscal year average to 2016 dollars to account for the time value of money. The mean funded level, for the three years, represents the average amount of funds allocated to SRM runway pavement projects between FY 14-16.

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The three funding levels represented a different financial environment. The funding levels were categorized as Low, Medium, and High. The Low funding level represented a constrained financial environment, which was established as half of the FY 14-16 average. The Low funding bucket communicates how many pavement slabs could be preserved, based on different condition goals and prioritizations, in a financially constrained environment. The Medium funding level was defined as the FY 14-16 average. The Medium funding level helps decision-makers decide how many pavement slabs could be replaced if the current financial limits remained in the next fiscal year. Finally, a High funding level value showed the pavement preservation level if more financial resources became available for the allocation of SRM projects. The High funding level was calculated as two times the average of the FY 14-16 funding values. For all funding levels, the pavement preservation level increased as more resources became available for these SRM projects, but the goal of the research was to determine how much additional preservation would be attained if more resources were present. Another goal was to determine how many resources would be needed to reach certain predetermined condition thresholds for the pavement system. The thresholds are explained in more detail later on, but could include a FOD index level no higher than 20, a PCI deduct value no higher than 10, or pavement slabs with a PCI less than 70.

Funding Strategy Analysis

The different funding levels were applied to the distress combination prioritization list to determine the amount of treated distressed slabs for each funding

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environment. The prioritization list ranked all of the different distress combinations based on the PCI deduct values. The PCI deduct prioritization list was the primary tool for the selective slab replacement funding strategy, but other metrics like the FOD index or PCI were also analyzed to determine what level of funding would be required to maintain a certain condition threshold. Selective slab replacement is a methodological approach to ensure that only the worst pavement slabs receive rehabilitation treatments. The selective nature of slab replacement works well in the Air Force's constrained financial environment. Instead of fixing the entire pavement system, only the slabs that need to be repaired receive the rehabilitation treatments. The research established the tools required to determine which decision-making process should be used to allocate the limited resources to slab replacement treatments.

The first step determined the cost associated with slab replacement on rigid runway pavement systems. RSMeans® *Building Construction Cost Data* determined the unit cost for slab replacement. RSMeans® has collected cost data for construction related tasks for 73 years, which supports the decision to select the text for this research. In addition, numerous locations and organizations across the United States use RSMeans® as the source for cost estimation. Area adjustment factors from RSMeans® were used based on the knowledge that location plays a large role for construction related costs. The area costs factors for each base were chosen based on the proximity to Air Force base.

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The condition threshold analysis determined how selective slab replacement impacts the condition of the Air Force's primary rigid runway pavement systems according to different funding level environments. The different funding levels help to determine the impact that different financial environments have on the preservation of the critical runway assets. The analysis developed the required costs, using selective slab replacement, to correct all of the currently distressed pavement sections to meet the desired condition goals. Condition thresholds for the research include a minimal PCI value for the pavement sections, a desired FOD index level for continuous mission operations, or a maximum PCI deduct score for distress combinations. The condition thresholds communicate the benefit of selective slab replacement over a complete reconstruction, or even the required resources to meet the desired condition levels. The funding levels established for this research include a maximum PCI deduction value of 10 for an individual distress combination, a maximum FOD index score of 20, and a minimum section PCI score of 70. The PCI deduct condition threshold developed the goal to correct any individual distress combinations with a PCI deduct value of 10 or greater. A pavement section can have any number of distress, severity, and density combinations. By correcting the distress combinations with a PCI deduct greater than 10, the chance of a single distress changing the overall condition rating of the pavement is minimized. Pavements are categorized by the PCI on a scale from "Failed" to "Good" (Colorado State University, n.d.). The pavement condition ratings provide a quick visual to decision-makers on the overall condition of the pavement. The goal of "no PCI deduct values of 10 or greater" minimizes the chance of a single distress combination changing

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the overall condition of the pavement, which could lead to asset management decisions based on only one observed distress.

The FOD index goal corrects any pavement sections with a FOD index greater than 20. FOD on primary runways impacts the mission operations, potential damage for Air Force weapon systems, and most importantly potential safety concerns for operators. A lower FOD index value is a better score and describes a pavement with a lower potential for the creation of FOD. According to Figure 3, the FOD index score begins to increase rapidly around a score of 20. By correcting all pavement sections with a FOD index greater than 20, decision makers correct FOD issues before the FOD level worsens. In addition, a FOD index score of 20 balances the tradeoff between acceptable risk tolerance and feasibility. A FOD index score of zero for all pavement sections is desired, but it is not feasible. A FOD index score of 20 relates to a PCI score of 80 for a pavement section, disregarding any distresses without the FOD creation possibility. A FOD index score of 20 may not be the ideal number for every Air Force base or mission set, but the score and findings give leadership the data needed to determine if the additional costs are worth an incremental reduction of possible FOD creation.

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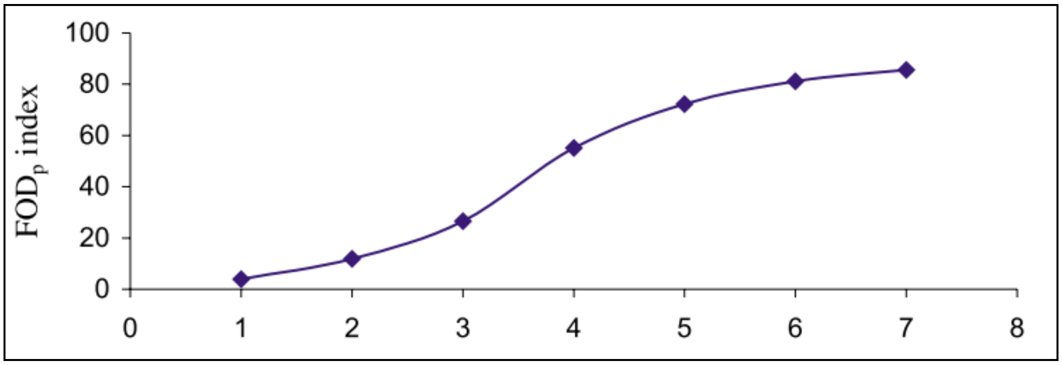

Figure 3: FOD Index in Relation to Pavement Age (Shah, 2004b)

The final condition goal focused on maintaining a PCI score of at least 70 for all pavement sections. The rate of deterioration begins to increase as the condition of the pavement is reduced. The critical condition for pavement systems is around a PCI of 70 (AFCEC, 2014). Figure 4 shows that after the pavement condition reaches an overall rating of “Fair,” equivalent to a PCI of 70, the costs to maintain the pavement increase and the condition of the pavement begins to decrease rapidly. The goal to maintain all pavement sections at a PCI of 70 of higher minimizes the risk of falling below the critical condition level.

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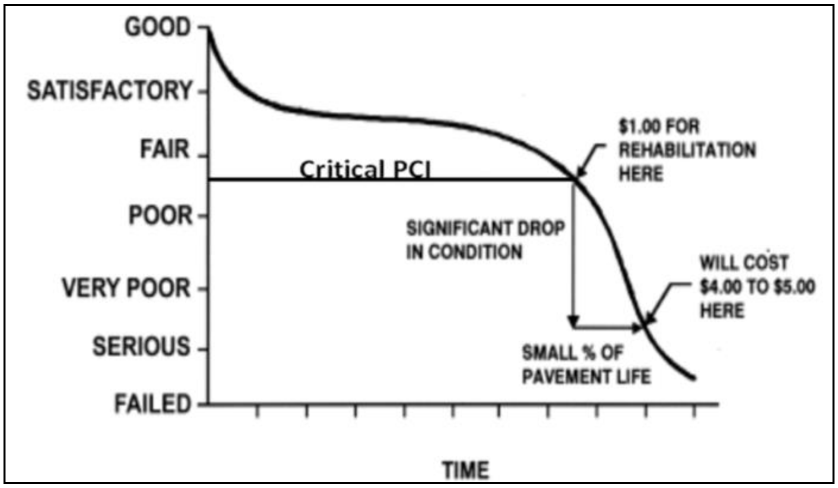

Figure 4: Pavement Deterioration Curve (AFCEC, 2014)

Funding Level Applicability

The final step in the methodology determined how many pavement distresses could be corrected in different funding environments. The application of the three funding levels to the PCI deduct prioritization list concludes how the funding levels impact the ability to correct the pavement distresses and maintain the Air Force's primary rigid runway systems. Obviously, more resources that are available led to more corrected distresses and an overall better condition of the pavement assets. The primary goal of this phase is not to support the obvious but rather to determine the incremental difference between funding scenarios. In addition, the outcome helps researchers determine if selective slab replacement is a better option for the preservation of rigid pavement assets in a constrained financial environment, compared to large-scale reconstruction projects in a financially abundant environment.

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The research included multiple assumptions during the final step of the data analysis. First, the assumption was made that pavement distresses did not change, in severity or density, from the most recent pavement inspection. The assumption accepts that the analyzed pavement sections had no additional distresses, and that no priority rankings or PCI deduct values changed since the most recent inspection. Additionally, the analysis assumed there would be additional slabs repaired from onsite visual inspection. The transportation of slab replacement teams to the construction site require large upfront costs. It makes financial sense to repair additional slabs that may not meet the prioritization metric but are located near the high priority slabs. The calculations included an added value of ten percent to account for the additional slabs to receive selective slab replacement assumption. This value may not be accurate for all bases, but the assumption was required based on the knowledge that additional slabs would receive corrective treatment that did not meet the prioritization cutoff. A pavement slab may have any number of distress type and severity combinations, but for this research, a slab was assumed to only have one observed distress. The Air Force pavement inspection reports included a total of 185,500 distressed slabs across the CONUS Air Force. In reality, there are fewer than 185,500 distressed slabs across the Air Force, but the assumption that each slab only had at max one distress led to numerous slabs being double counted for treatment calculations. Finally, the corrected PCI deduct scores were assumed to not apply for the PCI deduct calculations in the research. ASTM D5340-11 states to correct the PCI deduct values based by the maximum allowable number of distress (*m*) (ASTM D5340-11, 2011). The assumption that corrective PCI deduct values

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did not apply was made because of the previous assumption that a slab only has one observable distress. The assumptions are a conservative approach. In practice, slab replacement treatments could fix numerous observed distresses from the priority list with one slab replacement treatment.

The application of the funding level values to the PCI deduct prioritization list determined the condition impact of different funding environments on the rigid runway pavement sections. The analysis only corrected the slabs that had the observed distress with slab replacement. This approach ensures that only the pavement slabs that needed the repair received the resources and corrective slab replacement treatment. The distress densities were applied to the overall section size to determine the number of pavement slabs that had the distress. Next, the RSMeans® cost for slab replacement and the area adjustment factor, for each distressed slab, were used to calculate the total cost to replace all of the slabs that needed treatment. Each distress combination used the cost calculation process until the sum of the slab replacement treatments equaled the funding level values. The three funding levels were compared by the total number of slabs treated, the PCI of the remained pavement sections not treated, and the lowest distress combination priority rank treated.

The first comparison communicates to leadership how far resources stretch if the Air Force solely uses selective slab replacement for pavement preservation. The funding level comparison determines if selective slab replacement reaches a larger portion of distressed pavement sections compared to complete reconstruction. Next, the PCI of the untreated pavement sections described the condition of the primary rigid runways that

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had an observed distress but did not receive preservation treatment. The comparison communicates the condition state of the primary rigid runway assets across the Air Force. More resources may be required if the condition level does not satisfy an acceptable level for safe mission operations. Finally, the funding levels were compared by the lowest distress combination priority rank treated. The highest funding level bucket should correct more distress combinations, but the additional slabs treated may be a low priority compared to the other funding levels. For this outcome, decision-makers should decided not to request the additional resources to correct low priority combinations.

Chapter Summary

Chapter III outlined the data analysis procedures taken for the thesis research. The methodology walks through the steps to calculate the PCI deduct value for each distress type, density and severity combination, develop potential funding levels for the preservation of rigid primary runway systems, determine the resources required to maintain a desired condition threshold, and compare the pavement preservation between the three established funding levels. Each step focused on answering the main thesis goal "how do different funding strategies impact the amount of selective slab replacement that can be used to preserve the condition of Air Force primary rigid runway pavements?"

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IV. Results and Analysis

Chapter IV presents the results and analysis for the thesis research. The chapter covers the outcomes from the procedures outlined in the methodology. Chapter IV was divided into three sections, each section covered the results of a research question. The three sections discuss:

1. The prioritization list created from analyzing the different distress type, severity, and density combinations.
2. The three funding levels generated from past sustainment projects for Air Force runway assets.
3. The impact that different funding levels have on the preservation of primary rigid runway pavement systems.

The research team used all three sections to answer the research goal of determining how different funding strategies impact the ability to use selective slab replacement to preserve the condition of Air Force primary rigid runway pavement systems.

Pavement Distress Impact

The first section of the thesis research focused on the creation of a pavement distress priority list. Decision-makers require the priority list to allocate constrained resources to the most critical pavement assets. The Pavement Condition Index (PCI) deduct values were calculated using PAVER™ with data gathered from Air Force pavement inspection reports. Pavement distress densities from the Air Force pavement inspection reports aided in the creation of three distinct density bins: Low, Medium, and

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High. The density bin values for each distress are found in Appendix A. The values displayed in Appendix A represent the percent of the pavement section with the observed distress. The density values were only based on the observed density values from the inspection reports and are not related to the severity of the distresses. The values in parentheses are the number of observations for each distress type from the most recent pavement inspection report for 50 Continental United States (CONUS) Air Force bases.

The density bins, created from density values displayed in Appendix A, in addition to the distress type and severity led to the PCI deduct values calculations in PAVER™. The pavement distress priority list ranks the PCI deduct values from largest to smallest. The ranked list communicates the distress combinations that have the largest impact on the condition of the rigid pavement system. The calculated PCI deduct values for each distress combination are found in Table 1. Multiple pavement distresses have the same PCI deduct values for different density bin and severity level inputs. For example, joint seal damage has the same PCI deduct values across different density bins. For joint seal damage, the density is recorded as either zero or 100 percent. This unique method leads to similar values across different density bins. Shrinkage cracking, pumping, and popouts are unique in that the severity does not play a factor in the PCI deduct calculations. Each of these distresses reports the severity as “N/A” instead of the traditional “Low, Medium, or High” levels. The severity process for these three distresses leads to the same PCI deduct values across all of the severity bins.

The pavement distress priority list encompasses 111 distress combinations, ranging in value from 97.8 (high severity, high density shattered slab) to 1.0 (low

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severity/low density small patch). The prioritization list gives decision-makers a quick tool to determine what distresses to repair, or mitigate, to maintain the structural integrity of the pavement asset. The complete PCI deduct priority list can be viewed in Appendix B.

The priority list ranks all of the potential rigid pavement distress combinations by their impact to the condition of the pavement. This priority list should not be mistaken for the observed pavement distresses found on actual Air Force bases. For instance, the top priority pavement distress according to the PCI deduct priority list is a high severity, high density shattered slab. However, there were no observations of a high severity, high density shattered slab found on Air Force primary rigid runways. Therefore, the decision-makers still need to analyze observed pavement distresses at their bases to properly allocate resources for slab replacement.

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Table 1: PCI Deduct Values Air Force Rigid Primary Runway Pavements

PCI Deducts Values											
	Density	**Low**			**Medium**			**High**			
	Severity	**L**	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**	
Distress Type	JOINT SEAL DAMAGE (613)	2.0	7.0	12.0	2.0	7.0	12.0	2.0	7.0	12.0	**All CONUS Air Force Bases (50)**
	ASR (28)	5.0	14.0	23.1	11.9	32.3	51.8	21.8	49.9	81.9	
	SHRINKAGE CRACKING (369)	1.1			2.5			14.0			
	SCALING (137)	1.3	4.4	17.7	2.0	9.0	29.3	7.0	39.0	80.7	
	LINEAR CRACKING (452)	4.8	10.9	14.7	8.5	18.6	25.3	21.7	56.5	82.1	
	SHATTERED SLAB (73)	10.0	18.6	29.8	17.2	27.1	39.9	53.7	77.4	97.8	
	SMALL PATCH (836)	1.0	3.1	6.5	2.3	8.1	14.7	9.1	20.4	36.1	
	LARGE PATCH/UTILITY (415)	3.4	10.4	16.8	6.2	16.9	28.3	21.5	47.8	86.0	
	DURABILITY CRACKING (64)	3.4	10.0	17.3	8.6	21.1	37.0	20.2	42.5	75.6	
	JOINT SPALLING (625)	1.6	3.9	12.7	1.6	3.9	12.7	11.7	28.2	43.8	
	PUMPING (3)	10.0			14.5			14.5			
	CORNER SPALLING (451)	2.1	4.0	4.9	2.1	4.0	4.9	8.6	14.2	19.6	
	CORNER BREAK (116)	4.1	8.4	13.2	4.1	8.4	13.2	15.2	24.3	36.0	
	POPOUTS (38)	4.3			4.3			11.9			
	FAULTING (24)	4.6	8.0	15.4	4.6	8.0	15.4	8.5	14.3	26.1	

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Funding Levels

The next phase of the thesis research resulted in the creation of three different funding levels to determine how diverse funding environments impact the preservation of rigid primary runway pavement systems. Construction tasking orders from FY 2014-2016 established the amount of resources allocated to airfield correction and sustainment baseline for this research. Appendix C shows all of the projects from the FY 2014-2016 that focus with airfield pavement sustainment.

The amount of resources allocated to these pavement projects for the three fiscal years established the three different funding levels. For fiscal years 2014 and 2015, inflation values from the Bureau of Labor Statistics brought the funds to 2016 dollars. FY 14's total is higher than the other fiscal years due to a large airfield pavement project at Dover AFB for $81.2 million. This large project at Dover AFB was included in the funding level creation because of the possibility having large pavement projects in future years.

The average of the three fiscal year totals created the Low, Medium, and High funding levels. The funding levels represent either a financially constrained environment (Low), an average funding level (Medium), or a financially abundant environment (High). The Low funding level has a financial limit of $45 million, calculated as half of the FY14-16 average. The Medium funding level has a limit of $90 million. The average of the FY14-16 funds used on runway pavement preservation for the Air Force

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established the Medium funding level limit. Finally, the High funding level has a max funding limit of $180M. The High funding limit represents twice the Medium funding limit. All of the funding levels were calculated in 2016 dollars. The funding levels are used in the next phase of the research to determine how funding environments impact rigid airfield pavement preservation.

Pavement Preservation Strategies

The final phase of the thesis research focused on the impact that different funding levels have on the preservation of primary rigid runway pavement systems. The goal of this phase of the research focused on how many slabs would receive slab repair treatment in different funding environments. A recommended funding approach will be communicated at the conclusion of this phase of the research. The recommended funding approach was created after a thorough analysis of the impact that different funding levels have on the preservation of pavement sections, the amount of resources spent on past pavement projects, and the cost required to maintain different condition thresholds. RSMeans® *Building Construction Cost Data* calculated the unit cost of $22.22 per square foot for selective slab treatment (Fortier et al., 2015). Area cost factors for each location adjusted the total cost to repair each observed distress because of the knowledge that construction costs vary by location. The area adjustment factors for each location can be viewed in Appendix D. The area cost factors were selected by proximity to the Air Force Base, with the closest recorded adjustment factor being used in the final

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calculation. The total cost to replace all the slabs with the observed distressed was also increased by ten percent. The ten percent increase assumes that there would be additional slabs corrected once the repair team arrived onsite and corrected nearby distressed pavement slabs.

Funding Level Analysis

The primary analysis for the final phase of the research focused on the impact that the three funding levels had on pavement preservation. This phase of the research analyzed two different approaches. First, the priority-ranking list created during the first phase ranked the pavement distresses by PCI deduct. The first approach determined the level of pavement preservation if the decision-makers adopted the priority list. The next approach sorted the observed pavement distresses by the section PCI. This approach communicated how many pavement slabs received corrective slab repair treatment if decision-makers only focused on critical pavement sections.

The summary metrics from the priority ranking approach are found in the top half of Table 2. Each funding level outlined four key metrics: total cost for each funding scenario, highest priority rank treated, number of slabs repaired, and percent of all distressed pavement slabs in the Air Force treated. The total cost found in the summary metric table represents the amount of resources spent on selective slab treatment. The total cost values are slightly lower than the funding level amounts because the total costs found in the table are the highest amount of resources that could be spent without

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crossing the funding level constraint. In a low funding environment, $45 million was allocated for pavement repair and 1.9 percent of all distressed rigid pavement slabs received slab replacement treatment. Therefore, even in a financially constrained environment, the Low funding level resources restored the worst 1.9 percent pavement slabs with selective slab treatment. Next, in a medium funding environment consistent with the past three years' average, 3.8 percent of the distressed pavement slabs received selective slab treatment. Finally, the High funding level limit repaired 7.9 percent of the rigid pavement slabs with selective slab treatment.

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Table 2: Funding Level Summary Metrics

Funding Level Summary Metrics By Priority Ranking				
Funding Level	**Total Cost**	**Highest Priority Rank Treated**	**# Slabs Repaired**	**Percent of Slabs Repaired**
Low	$ 45,000,000	31	3,600	1.9%
Medium	$ 90,000,000	31	7,100	3.8%
High	$ 180,000,000	42	14,600	7.9%
Funding Level Summary Metrics By Section PCI				
Funding Level	**Total Cost**	**Lowest PCI Corrected**	**# Slabs Repaired**	**Percent of Slabs Corrected**
Low	$ 44,700,000	30	3300	1.8%
Medium	$ 90,000,000	38	6600	3.6%
High	$ 173,000,000	54	12900	7.0%

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The second research approach applied funding level limits constraints to the pavement distress list, sorted by section PCI. This approach focused on the worst condition pavement sections first, treating the most critical pavement sections without factoring the priority rank of the observed distress. Pavement sections, in an ideal environment, should be maintained above the critical PCI level of 70. After the condition of the pavement section falls below 70, the pavement deterioration rate begins to increase. The research approach prioritized the slabs by section PCI to correct the most critical pavement slabs first and minimize the amount of pavement sections that have fallen below the critical condition level. Four key summary metrics were calculated from the section PCI priority analysis: total cost for selective slab treatment, lowest section PCI corrected, number of slabs repaired, and percent of pavement slabs that received selective slab treatment. The results from the section PCI prioritization ranking are also presented in Table 2. The section PCI prioritization summary metrics are shown in the bottom half of the table.

The funding level analysis results led to multiple conclusions for this research. First, the priority ranking system ensures that the most distressed pavement slabs are corrected first. Next, in a high funding level, almost eight percent of the highest priority pavement slabs received selective slab treatment. This equates to 14,600 slabs across the CONUS Air Force bases. Finally, selective treatment guarantees that resources are only spent on high priority pavement slabs that required corrective treatment. The selective slab replacement results provide the support needed to move away from the traditional

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funding approach, of repairing the entire airfield, to a more selective treatment approach. The selective treatment approach, in the form of slab replacement, allows for the repair of a large number of high priority pavement slabs even in a financially constrained environment.

Condition Thresholds

The next phase of the research analyzed the amount of resources required to maintain predetermined condition thresholds. The condition thresholds include: correct all distresses with a PCI deduct greater than 10, fix all pavement distresses found on pavement sections with a PCI below the critical level of 70, and repair all pavement distresses observed on pavement sections with a FOD value greater than 20. The condition levels focus on important metrics that measure the overall condition of the pavement system. A distress with a PCI deduct greater than ten immediately changed the condition level of the pavement system. The pavement deterioration rate increases after the PCI falls below the critical level of 70. Finally, research shows that the FOD level increases at a faster rate after the pavement section's FOD index passes a value of 20 (Anw Shah, Ar, Tighe, & Stewart, 2004). Condition thresholds communicate the amount of resources required to maintain a predetermined condition and provide decision-makers the data necessary to make key financial decisions regarding the preservation of critical Air Force runway systems. The summary metrics for each condition threshold are shown in Table 11 found in Appendix F. Table 11 shows the description for each condition

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threshold, the total cost required to correct all slabs using selective slab treatment, the highest priority ranked distress treated, the number of slabs that fit the condition threshold requirement, and the total percent of pavement slabs out of all distressed slabs that received treatment for each condition threshold.

The condition analysis treated all distressed slabs meeting the condition threshold requirement with selective slab replacement. If decision makers opt to use condition thresholds for resource allocation, a large number of slabs would receive slab replacement treatment that may not have needed it. The PCI and FOD goals corrected all pavement slabs that met each condition description. Consequently, if a pavement slab met the condition description, the slab received selective slab replacement even if the observed distress was a low priority. This limitation led to an inefficient use of Air Force resources that did not necessarily target the highest priority distresses and worst conditioned slabs. Therefore, condition goals are not the recommended funding approach because of the inefficient use of resources and large costs.

Base Comparison

Selective treatment methods are a relatively new approach to repair pavement systems. In the past, the Air Force used large-scale projects to repair entire airfields at once. The traditional method led to large project costs, a long operational down time, and the treatment of slabs that did not need corrective treatment. Dover AFB's airfield repair project of $81.2 million shows the costs associated with the traditional repair method.

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The research also analyzed a project at Columbus AFB of $12 million, in addition to the Dover AFB project. The traditional base project analysis determined the preferred funding approach between large repair projects compared to selective slab replacement.

The three scenarios compared the selective slab replacement costs to the costs associated with large-scale projects at Dover AFB and Columbus AFB. The first scenario determined the total cost to slab repair all primary rigid runway pavement slabs that had an observed distress for both bases. Next, the traditional project amounts were applied to the distress priority list created for the entire Air Force. This phase of the research analyzed both distress priority ranking and section PCI lists to compare the traditional reconstruction projects to the pavement condition impact with selective slab replacement. The results of the base comparison are presented in Table 3. The description column defines the scenarios described above and the total costs column highlights the total costs associated with each scenario. The highest treated column contains the description of the highest distress priority reached, or the highest section PCI corrected, for the scenarios.

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Table 3: Base Large Project Comparison Metrics

Base Project Comparison Metrics				
Description	**Total Cost**	**Highest Treated**	**# Slabs Repaired**	**Percent of Slabs Repaired**
Dover Funding Limit ($81,200,000)	$ 1,500,000,000	All Distresses Corrected	18,600	100%
$81,200,000 Ranked by Distress Priority	$ 80,600,000	31 - Linear Crack	6,300	3.4%
$81,200,000 Ranked by Section PCI	$ 81,000,000	PCI 36	6,000	3.2%
Columbus Funding Limit ($12,000,000)	$ 77,000,000	All Distresses Corrected	1,500	100%
$12 Mil Ranked by Distress Priority	$ 11,000,000	104 - Corner Spall	2,300	15.3%
$12 Mil Ranked by Section PCI	$ 12,000,000	New PCI 85	1,800	11.4%

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The base comparison presented in Table 3 shows the impact that selective slab repair has compared to the traditional large project funding approach. The Dover AFB project amount was applied to all of the distressed slabs across the Air Force, compared to the Columbus AFB project amount, which was only applied to the distressed slabs at Columbus AFB. Although the Dover comparison treated 3.4 percent of the distressed slabs, the treated slabs are the worst conditioned slabs across the entire Air Force. This single project also treated all pavement sections slabs with a PCI less than 36.

The Columbus AFB project to repair the outside runway of 13L/31R was compared to the amount of resources spent on selective slab repair for the distressed rigid runway slabs at Columbus AFB. The cost associated with repairing the outside runway of 13L/31R was $12 million. However, the cost associated to selective slab repair all distressed rigid runway pavement sections at Columbus AFB was $77 million. If decision-makers used project resources on selective slab replacement, 15.3 percent of the distressed slabs would be treated. The distress ranking of 104 (Corner Spall) communicates that 84.7 percent of the distressed slabs not treated are a very low priority and may not need treatment. Finally, if decision makers focused on the section PCI ranking, all of the distressed slabs at Columbus AFB with a PCI below 85 would receive selective slab treatment.

The Dover AFB and Columbus AFB comparisons show the great potential for selective slab treatment compared to the traditional approach of large airfield reconstruction projects. Only the worst conditioned pavement assets received slab

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replacement treatment if decision-makers used a selective treatment approach instead of traditional repair projects. The selective treatment approach corrects 3.4 percent of the Air Force's worst pavement slabs if the Dover AFB project funds are used with a selective treatment approach instead of the traditional airfield repair method. Additionally, selective slab repair using the Columbus AFB project funds correct all rigid runway pavement slabs that had a section PCI below 85. In a financially constrained environment, leadership should consider all options to ensure that the resources are spent efficiently. The base project comparison led to the conclusion that selective slab replacement allocates resources more efficiently than traditional large reconstruction projects to correct the worst condition pavement slabs.

Air Force Recommended Treatments

The Air Force established an M&R treatment list for all distress types and severity levels. The Air Force list gives base pavement engineers the recommended treatment options and associated costs for how to preserve the pavement systems. Thus far, selective slab replacement was the only treatment considered for distressed pavement slabs. This portion of the research focuses on the Air Force recommended treatment list costs compared to selective slab replacement. The Air Force recommended treatment list contains corrective treatments (Slab Replacement, etc.), preventive treatments (Crack Seal, Joint Seal, etc.), and recommendations to do nothing at all. The complete Air Force recommendations list can be viewed in Appendix E.

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Multiple assumptions were made because of the nature of preventive treatment options. Treatment options, such as crack sealing, are measured by the linear foot instead of density, as reported in the pavement inspections. Therefore, assumptions were required for distresses that are measured by the linear foot. For linear cracks, the calculations assumed that the crack extended throughout the entire length of the slab. Also, corner breaks were assumed to extend from the midpoint of the slab width to the midpoint of the slab. Furthermore, the analysis assumed that joint spalls, joint seal damage, pumping, and faulting occurred along the entire perimeter of the pavement slab. Next, all small patch distresses were assumed to cover 5.5 square feet (SF) of each distressed slab. The PAVER™ *Distress Identification Manual* defines a small patch as any patch less than 5.5 SF, and a large patch as greater than 5.5 SF (US Army Corps of Engineers, 2009). Therefore, the assumption that all small patches were 5.5 SF was a conservative one. Finally, we assumed that large patches equaled the distress density for each pavement slab. For example, a density of 2 percent on a 625 SF (25Ft x 25 Ft) pavement slab equates to a large patch distress size of 12.5 SF. All of the assumptions accounted for the worst-case scenario and errored on the side of caution.

The analysis includes the summary output for the Air Force recommended treatments for each observed distress in Appendix F. The total cost to repair all distressed slabs with the Air Force's recommended treatment methods came out to $20.5 million. The analysis shows that the Air Force recommended treatment costs are low for the treatment of all distressed slabs, but low priority slabs still received treatment. The

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low priority treatment led to an inefficient use of resources. Therefore, the next analysis calculated the costs of Air Force recommended treatments if used efficiently to treat high priority pavement slabs. Three scenarios were analyzed to include: treat all distressed slabs with a section PCI less than 70, treat all distressed slabs with a distress that leads to a PCI deduct value greater than 10, and a combination of both. The summary metrics for the three comparisons are found in Appendix F. The comparison determined that the Air Force recommended treatments require minimal resources, but the Air Force recommended treatments focus on preventive treatments instead of corrective slab replacement. Therefore, the results lead to the recommendation that asset managers should not solely rely on Air Force treatments because of the preventive approach compared to the corrective measures from slab replacement.

Air Force Recommended Treatment Findings

Five distress type combinations had an Air Force recommended treatment that did not match appropriately with the distress priority ranking. The five distress types are a medium severity linear crack, low severity shattered slab, low severity Alkali Silica Reaction (ASR), low severity linear crack, and low severity durability crack. The five distress type findings are presented in Appendix G. Five distress types were highlighted because of the high priority ranking in the priority list but minimal M&R treatment from the Air Force recommended treatment options. Each of the distresses leads to a high PCI deduct value, which leads to a significant impact on the pavement slabs. The Air Force

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recommended treatment anomalies was an unexpected finding, but the observation is a significant one nonetheless. To manage the Air Force decaying pavement assets, data must be collected and used accordingly to ensure the treatment methods fit the observed distresses on the pavement slabs. The findings lead to the recommendation that selective slab treatment should be used for the five distresses instead of the Air Force recommended treatments. Slab replacement ensures that no increase in severity would occur for the five distresses and that their impact on the pavement condition would be minimized.

Research Funding Recommendation

The final subchapter focused on the recommended funding approach for the selective treatment of rigid primary runway pavement slabs. Treating all distressed rigid runway slabs with selective slab treatment has the largest impact on condition improvement, but solely relying on selective slab repair also costs more than the Air Force recommended treatment options. Additionally, condition thresholds are a great starting point for prioritization, but these approaches are inefficient as numerous slabs in relatively good condition meet the treatment cutoff. Therefore, the results and analysis lead to the recommendation that asset managers should use a combination of preservative treatment and selective slab replacement to preserve Air Force's primary rigid runway pavement slabs.

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First, all medium and high severity joint seal damager should be repaired with joint seal repair. The joint seal repair treatment cost for every slab across the Air Force would be $11.5 million, using conservative assumptions. Next, all distressed pavement slabs with a section PCI less than 70, and with an observed distress with a PCI deduct greater than 10, should receive selective slab replacement. The total cost for selective slab repair on these slabs is $110 million. These two treatment measures would cost a total of $122 million, well below the high funding level. Any additional funds remaining from these two measures should be spent on preventive treatments from the Air Force recommended treatment list. This recommended funding approach minimizes FOD potential created from joint seal damage, uses corrective measures in the form of selective slab replacement to repair the worst conditioned and highest priority pavement slabs, and reduces further condition degradation with the Air Force recommended treatment table. The recommended approach ensures the efficient use of funds in a financially constrained and uncertain environment. Table 4 breaks out each possible funding scenario, along with the highest priority treated and the total percent of slabs repaired out of the Air Force total.

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Table 4: Recommended Funding Approach Summary Metrics

Recommended Funding Approach Summary Metrics				
Description	**Total Cost**	**Highest Priority Rank Treated**	**# Slabs Repaired**	**Percent of Slabs Repaired**
PCI < 70 & PCI Deduct >10	$ 110,000,000	54	9,000	4.8%
Joint Seal Repair (High/Med Severity Joint Seal Damage)	$ 11,500,000	N/A	36,800	19.8%
Joint Seal Repair (High) & Slab Replace PCI Deduct >10	$ 177,000,000	65	40,000	21.8%
Joint Seal Repair (High) & Section PCI <70	$ 284,000,000	104	35,000	18.9%
Joint Seal Repair (High/Med), PCI <70, PCI Deduct >10	$ 122,000,000	54	45,800	24.7%

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Chapter Summary

Chapter IV presented the data results and analysis for the thesis research. The results and analysis methodology walked through the creation of a pavement distress priority list, the development of different funding levels based on past funded pavement projects, and the selective slab treatment analysis based on different condition metrics and funding levels. From the results and analysis of these steps, the research team presented the overall funding approach recommendation to ensure that the highest priority pavement slabs are treated appropriately in a financially uncertain environment. The researchers recommend to treat all medium and high severity joint seal damage with joint seal repair, use selective slab treatment on all pavement slabs with a section PCI less than 70 with a distress deduct value greater than ten, and allocate all remaining funds on preservative treatments from the Air Force recommended treatment list.

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V. Results and Analysis

Chapter V discusses the conclusions for the research. Chapter V was divided into three sections to include: Results of Research, Limitations, and Future Research. The first section covers the results of the research, and how the results specifically answer the three research questions presented in Chapter I. The next section presents the limitations that the research team found during the thesis research. The final section of Chapter V discusses possible future research topics.

Results of Research

The research effort sought to answer the main research question, "How do different funding strategies impact the amount of selective maintenance and rehabilitation treatment that can be used to preserve the condition of Air Force primary runway pavements"? To answer the main research question, the researchers answered three sub-questions:

1. How do different pavement distress types, densities, and severities impact the condition of rigid pavement assets?
2. How do different funding environments affect the amount of selective slab replacement on Air Force's primary rigid runway pavement systems?
3. What is the recommended selective maintenance and rehabilitation treatment approach to preserve the Air Force's primary rigid runway pavement systems?

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The first research question focused on the observed pavement distresses recorded on Air Force pavement inspection reports. Each pavement distress combination leads to a different Pavement Condition Index (PCI) deduct value and impacts the condition of the pavement system. Air Force pavement inspection reports provided the pavement distress data to determine the PCI deduct values for every possible pavement distress combination. The calculated PCI deduct values led to the creation of a prioritization list to aid decision-makers with the allocation of pavement preservative resources. The prioritization list ranks the pavement distress combination PCI deduct values based on the impact that the distress has on the pavement system. The list gives decision-makers a quick reference to support pavement preservation resource allocation and treatment projects. The full priority list can be viewed in Appendix B.

The second research question developed three different funding levels based on past runway pavement preservation projects for FY 14-16. Three funding levels: Low, Medium, and High led to the comparison between the different resource constraints and ability to treat the observed pavement distresses across CONUS Air Force bases. Selective slab replacement was chosen for corrective treatment on the distressed rigid airfield pavement slabs. The total cost calculation used a slab replacement cost of $22.22/SF from RSMeans® *Building Construction Cost Data* and corrected the cost with area adjustment factors according to the base geographical location (Fortier et al., 2015). The three funding levels represent a financially constrained funding environment (Low), an average funding environment (Medium), and a financially abundant funding

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environment (High). If the Air Force solely used selective slab replacement for primary rigid runway pavement slabs, 1.9 percent of all distressed slabs across CONUS Air Force bases would be corrected in a Low funding environment. In a Medium funding environment, 3.8 percent of the distressed rigid pavement slabs received slab replacement treatment. Finally, a financially abundant funding environment provided enough resources to correct 7.9 percent of all distressed rigid pavement slabs with slab replacement treatment. The results may seem low at first glance, but the selective slab replacement treatment approach using the distress combination prioritization list corrects the worst conditioned pavement slabs in the CONUS Air Force. Therefore, the corrective slab replacement treatment completely repaired the highest priority, worst conditioned pavement assets on the Air Force's critical runway pavement systems. The results from the funding level comparison communicate the efficient use of resources with selective slab replacement treatment using the distress combination prioritization list.

The third research question focused on the recommended funding and treatment approach, given the funding level limits. Ideally, all distressed slabs receive corrective slab replacement treatment. After analyzing the results though, there are insufficient funds to treat all distressed slabs with slab replacement treatment. Therefore, the recommended treatment approach utilizes a combination of slab replacement and preservative Air Force recommended treatments. First, joint seal repair treatment should be used to treat all medium and high severity joint seal damage on primary rigid runway pavement slabs. Next, decision-makers should treat all distressed slabs with slab

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replacement that had a PCI less than 70 and an observed distress PCI deduct score greater than 10. The total cost of the two M&R treatments was $121.5 million, well below the High funding limit. All remaining funds available for the year would then be allocated to treat untreated distressed pavement slabs with the Air Force recommended preventive treatments. Appendix H presents a decision tree for the recommended treatment approach strategy. The recommended funding approach minimizes FOD potential created from joint seal damage, uses corrective measures in the form of selective slab replacement to repair the worst conditioned and highest priority pavement slabs, and reduces further condition degradation with the Air Force recommended treatment table. The recommended approach ensures the efficient use of funds in a financially constrained and uncertain environment.

The final conclusion for the research focused on a strategy of how to conduct the recommended treatment approach across CONUS Air Force bases. The repair strategy needs to focus on minimal operational down-time. Therefore, asset managers should implement the recommended treatment approach during no-fly weekends and holidays to apply the recommended treatment approach to the distressed slabs. Type I (General Purpose) concrete has a minimum cure time of seven days while the Type III (High Early Strength) concrete only requires three days to cure (ACI 308R-01, 2001). Therefore, the use of no-fly days allows the concrete slab to reach acceptable compressive strength with minimal impact to mission operations. Furthermore, asset managers should use a specialized Air Force selective slab replacement teams for all Air Force slab replacement

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treatment and indefinite delivery/indefinite quantity (IDIQ) contracts for the implementation of the remaining Air Force recommended treatments. The specialized slab replacement team would solely focus on the slab replacement of the highest priority distressed slabs across the Air Force. The use of a specialized team would minimize costs, minimize treatment time, and increase the quality of the slab replacement treatment. Next, IDIQ contracts should be used for all remaining Air Force recommended M&R treatments for distressed slabs that did not receive slab replacement resources. The Air Force uses IDIQ when a specified quantity cannot be determined over a specified amount of time (Under Secretary of Defense (Comptroller), 2011). The use of IDIQ also streamlines the contractual process to speed up the delivery of the service. The recommended treatment approach defines the criteria, distress type, and treatment method for all distress options on Air Force primary rigid runway pavement systems, but the amount of treatment required may vary year-to-year. Therefore, an IDIQ contract provides a streamlined allocation of the recommended treatment approach in a financially uncertain environment.

Limitations

One limitation of the research includes the recommended treatment approach application to other branch uses (Taxiways, Aprons, Overruns) and ranks for Air Force airfields. The results only included data from primary rigid runway pavement systems on CONUS Air Force bases. Therefore, the conclusions from the research apply to a large

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portion of the critical pavement assets but not all of the pavement systems in the Air Force inventory. From this research, the prioritization list and treatment conclusion can only apply to primary rigid runways on airfields, and asset managers would have no data to support treatment approaches for the other pavement structure types, traffic levels, or ranks. A similar analysis approach could be used for pavement systems not covered in the research. The analysis of different pavement systems is necessary for a treatment approach conclusion that covers all Air Force airfield assets.

The creation of different funding levels led to another limitation in the research. The funding levels were based on past funded pavement projects, but the past projects were only gathered from the three most recent fiscal year. The three fiscal years provided a sample that that established the funding level values, but there is a chance that the three years do not represent the average funded amount for pavement preservation projects. Additionally, pavement projects included in the funding limit calculations were selected based on the project title alone. The project title provided sufficient information to determine if the project focused on runway pavement systems, but the selected projects were not narrowed down further in regards to pavement type or traffic type. Additionally, the project title selection process did not provide additional information regarding how much of the project dollar amount was allocated to only corrective treatment on primary runways. Furthermore, the fiscal year averages included the large Dover AFB airfield reconstruction project of $81 million. The large project cost increased the funding levels for all three buckets and may not represent the average

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funded amount for a typical FY. That being said, large airfield repair projects are still used in the Air Force, the inclusion of a large repair project could occur in the future and should be included in the funding limit calculations.

The final limitation stems from the assumption that a pavement slab only had one distress. The Air Force pavement inspection reports show a total of 185,500 distressed slabs across the CONUS Air Force. In reality, fewer than 185,500 slabs had an observed distress but the assumption led to slabs being counted twice for total treatment calculations. Additionally, the PCI deduct calculations are made in PAVER™ under the assumption that a slab has numerous distresses that interact together to worsen the overall pavement condition. The assumption led to a higher PCI deduct value for individual pavement distresses used in the prioritization list. However, the double counting of slabs led to a conservative cost calculation because more slabs receive treatment than actually have distresses compared to the Air Force pavement inspection reports. Therefore, the assumption led to PCI deduct values that may not exactly represent the PCI impact but the treatment approach uses conservative values to determine how many total slabs would receive corrective treatment.

Future Research

The final section of Chapter V covers potential areas for future academic research. The research only analyzed the upfront costs for selective slab replacement treatment. In addition to the upfront costs associated with the M&R treatment, equivalent

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annual cost data provides key insight to decision-makers when comparing treatment options. The annual costs of slab replacement compared to other treatment options could potentially show the minimal yearly costs associated with slab replacement compared to treatments that only prevent further deterioration. Equivalent annual cost is a great metric of comparison to determine the least expensive treatment method over the life of the treatment. The results and analysis only focused on primary rigid runway pavement systems, due to the mission criticality of these pavement assets. However, preventive resources are used every year to correct and treat flexible pavement systems on taxiways, aprons, overruns, and shoulders. Future research needs to analyze the historic costs associated with correcting distressed pavement systems that are not covered in the conclusions of this research.

Additionally, the results only analyzed the costs associated with the various M&R treatment methods. Future researchers should consider the analysis of the condition impact that the M&R treatments have on pavement systems, both flexible and rigid. Each M&R treatment impacts the PCI deduct because of the change in distress severity. Future researchers should analyze the improvement of the distress severity based on the different M&R treatments and the subsequent increase in system service life. Along with immediate PCI increase, the pavement deterioration rates change based on the condition of the pavement and M&R treatment program. Researchers can gather data to determine the impact that different M&R treatment methods have on the pavement deterioration rates for Air Force airfield pavement systems.

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Finally, minimal operational down-time is a key benefit of selective M&R treatment methods. Instead of shutting down the airfield for months or years, the airfield can receive needed repair treatment over weekends or holidays. Future researchers need to analyze the operational down-time comparison between different treatment methods and compare these times with large scale airfield reconstruction projects. For high priority missions, where the airfield must be maintained and open for mission success, the choice to use selective treatments may be the overall conclusion regardless of the costs associated with the treatments.

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Appendix A: Pavement Distress Density Values

Table 5: Pavement Distress Density Values

PAVEMENT DISTRESS DENSITY VALUES (Percent of pavement section with observed distress)						
Distress Description	Minimum	1st Quartile	Median	3rd Quartile	Maximum	
ASR (28)	0.1	1.9	5.5	18.6	100	All CONUS AFB's (50)
CORNER BREAK (116)	0.1	0.4	0.7	1.4	15.4	
CORNER SPALLING (451)	0.1	0.5	1.0	1.9	25.0	
DURABILITY CRACKING (64)	0.0	0.8	2.7	11.9	74.6	
FAULTING (24)	0.2	0.4	0.7	0.9	8.3	
JOINT SEAL DAMAGE (613)	0.8	25.0	55.5	100	100	
JOINT SPALLING (625)	0.1	0.7	1.5	3.2	52.1	
LARGE PATCH/UTILITY (415)	0.0	0.8	2.0	5.1	89.4	
LINEAR CRACKING (452)	0.1	1.1	2.6	8.3	86.1	
POPOUTS (38)	0.1	0.4	0.9	3.1	15.3	
PUMPING (3)	7.9	7.9	10.3	10.4	10.4	
SCALING (137)	0.1	0.7	2.0	6.7	100	
SHATTERED SLAB (73)	0.0	0.8	1.7	7.6	81.8	
SHRINKAGE CRACKING (369)	0.1	1.5	4.2	13.4	100	
SMALL PATCH (836)	0.0	1.1	3.3	10.1	70.0	

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Appendix B: Distress Combination Priority List

Table 6: Pavement Distress Priority List

Pavement Distress Priority List				
Distress Description	**Severity**	**Density**	**PCI Deduct**	**Ranking**
Shattered Slab	High	High	97.8	1
Large Patch	High	High	86.0	2
Linear Cracking	High	High	82.1	3
ASR	High	High	81.9	4
Scaling	High	High	80.7	5
Shattered Slab	Med	High	77.4	6
Durability Crack	High	High	75.6	7
Linear Cracking	Med	High	56.5	8
Shattered Slab	Low	High	53.7	9
ASR	High	Med	51.8	10
ASR	Med	High	49.9	11
Large Patch	Med	High	47.8	12
Joint Spalling	High	High	43.8	13
Durability Crack	Med	High	42.5	14
Shattered Slab	High	Med	39.9	15
Scaling	Med	High	39.0	16
Durability Crack	High	Med	37.0	17
Small Patch	High	High	36.1	18
Corner Break	High	High	36.0	19
ASR	Med	Med	32.3	20
Shattered Slab	High	Low	29.8	21
Scaling	High	Med	29.3	22
Large Patch	High	Med	28.3	23
Joint Spalling	Med	High	28.2	24
Shattered Slab	Med	Med	27.1	25
Faulting	High	High	26.1	26
Linear Cracking	High	Med	25.3	27
Corner Break	Med	High	24.3	28
ASR	High	Low	23.1	29

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ASR	Low	High	21.8	30
Linear Cracking	Low	High	21.7	31
Large Patch	Low	High	21.5	32
Durability Crack	Med	Med	21.1	33
Small Patch	Med	High	20.4	34
Durability Crack	Low	High	20.2	35
Corner Spalling	High	High	19.6	36
Shattered Slab	Med	Low	18.6	37
Linear Cracking	Med	Med	18.6	38
Scaling	High	Low	17.7	39
Durability Crack	High	Low	17.3	40
Shattered Slab	Low	Med	17.2	41
Large Patch	Med	Med	16.9	42
Large Patch	High	Low	16.8	43
Faulting	High	Low	15.4	44
Faulting	High	Med	15.4	45
Corner Break	Low	High	15.2	46
Linear Cracking	High	Low	14.7	47
Small Patch	High	Med	14.7	48
Pumping	N/A	Med	14.5	49
Pumping	N/A	High	14.5	50
Faulting	Med	High	14.3	51
Corner Spalling	Med	High	14.2	52
ASR	Med	Low	14.0	53
Shrinkage Cracking	N/A	High	14.0	54
Corner Break	High	Low	13.2	55
Corner Break	High	Med	13.2	56
Joint Spalling	High	Low	12.7	57
Joint Spalling	High	Med	12.7	58
Joint Seal Damage	High	N/A	12.0	59
Popouts	N/A	High	11.9	60
ASR	Low	Med	11.9	61
Joint Spalling	Low	High	11.7	62
Linear Cracking	Med	Low	10.9	63
Large Patch	Med	Low	10.4	64
Shattered Slab	Low	Low	10.0	65
Durability Crack	Med	Low	10.0	66
Pumping	N/A	Low	10.0	67

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Small Patch	Low	High	9.1	68
Scaling	Med	Med	9.0	69
Corner Spalling	Low	High	8.6	70
Durability Crack	Low	Med	8.6	71
Linear Cracking	Low	Med	8.5	72
Faulting	Low	High	8.5	73
Corner Break	Med	Low	8.4	74
Corner Break	Med	Med	8.4	75
Small Patch	Med	Med	8.1	76
Faulting	Med	Low	8.0	77
Faulting	Med	Med	8.0	78
Joint Seal Damage	Med	N/A	7.0	79
Scaling	Low	High	7.0	80
Small Patch	High	Low	6.5	81
Large Patch	Low	Med	6.2	82
ASR	Low	Low	5.0	83
Corner Spalling	High	Low	4.9	84
Corner Spalling	High	Med	4.9	85
Linear Cracking	Low	Low	4.8	86
Faulting	Low	Low	4.6	87
Faulting	Low	Med	4.6	88
Scaling	Med	Low	4.4	89
Popouts	N/A	Low	4.3	90
Popouts	N/A	Med	4.3	91
Corner Break	Low	Low	4.1	92
Corner Break	Low	Med	4.1	93
Corner Spalling	Med	Low	4.0	94
Corner Spalling	Med	Med	4.0	95
Joint Spalling	Med	Low	3.9	96
Joint Spalling	Med	Med	3.9	97
Durability Crack	Low	Low	3.4	98
Large Patch	Low	Low	3.4	99
Small Patch	Med	Low	3.1	100
Shrinkage Cracking	N/A	Med	2.5	101
Small Patch	Low	Med	2.3	102
Corner Spalling	Low	Low	2.1	103
Corner Spalling	Low	Med	2.1	104
Scaling	Low	Med	2.0	105

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Joint Seal Damage	Low	N/A	2.0	106
Joint Spalling	Low	Low	1.6	107
Joint Spalling	Low	Med	1.6	108
Scaling	Low	Low	1.3	109
Shrinkage Cracking	N/A	Low	1.1	110
Small Patch	Low	Low	1.0	111

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Appendix C: FY 14-16 Funded Air Force Pavement Projects

Table 7: FY 14-16 Funded Pavement Treatment Projects

FY 14-16 Funded Pavement Treatment Projects			
Installation	**Project Title**	**Cost**	**Fiscal Year**
VANCE AIR FORCE BASE	REPAIR OUTSIDE RUNWAY AND TAXIWAYS	$ 2,869,554.00	FY 14
MOODY AIR FORCE BASE	RPR AIRFIELD PAVEMENTS	$ 100,000.00	FY 14
BARKSDALE AIR FORCE BASE	Repair Airfield Pavement	$ 530,000.00	FY 14
RANDOLPH AIR FORCE BASE	Repair/Replace South End of West Runway 14R/32L	$ 1,500,000.00	FY 14
HILL AIR FORCE BASE	REPAIR (N) ASPHALT PAVEMENT RW 14-32 BAK-12 TO BAK-14	$ 5,000,100.00	FY 14
DOVER AIR FORCE BASE	REPAIR (SUS) RUNWAY 01/19	$ 81,200,000.00	FY 14
BARKSDALE AIR FORCE BASE	Repair Airfield Pavement, FY12, Phase 2	$ 2,000,000.00	FY 14
THULE AIR BASE	REPAIR RUNWAY PAVEMENT, PH1	$ 15,000,000.00	FY 14
BARKSDALE AIR FORCE BASE	Construct/Repair Runway 15, Threshold and Approach Lighting	$ 1,000,000.00	FY 14
BARKSDALE AIR FORCE BASE	Repair Runway Transition Area, Bravo to Echo	$ 110,000.00	FY 14
DAVIS-MONTHAN AIR FORCE BASE	Rpr Pavements (Airfield) - 5YP	$ 1,250,000.00	FY 14
MOUNTAIN HOME AIR FORCE BASE	Repair Runway 12/30, Mill/Overlay	$ 17,000,000.00	FY 14
MALMSTROM AIR FORCE BASE	RHS Repair Pavements	$ 300,000.00	FY 15
VANCE AIR FORCE BASE	REPAIR OUTSIDE RUNWAY AND TAXIWAYS	$ 34,000,000.00	FY 15
DAVIS-MONTHAN AIR FORCE BASE	Rpr Pavements Airfield, Multi Facs	$ 650,000.00	FY 15
MOODY AIR FORCE BASE	RPR AIRFIELD PAVEMENTS	$ 11,100,000.00	FY 15
BARKSDALE AIR FORCE BASE	Repair Airfield Pavement, Row F Site 1-4	$ 1,800,000.00	FY 15
TYNDALL AIR FORCE BASE	REPAIR AIRFIELD PAVEMENTS	$ 6,860,775.00	FY 15
PATRICK AIR FORCE BASE	Repair/Replace West End Section, RWY 11/29	$ 3,600,000.00	FY 15
BARKSDALE AIR FORCE BASE	Repair Airfield Pavement	$ 1,000,000.00	FY 15
CHARLESTON AIR FORCE BASE	RPR (R&M) C17 LANDING ZONE - NAAF	$ 12,000,000.00	FY 15
MOODY AFB	RPR AIRFIELD PAVEMENTS	$ 1,350,000	FY 16
OFFUTT AFB	RPR RUNWAY, MPA	$ 7,500,000	FY 16
COLUMBUS AFB	REPAIR OUTSIDE RWY 13L/31R	$ 12,000,000	FY 16

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LAUGHLIN AFB	REPAIR OUTSIDE RUNWAY	$ 662,900	FY 16
WHITEMAN AFB	AFL-NRF: Rpr Runway, Taxiway Slabs and Seal Joints, Phase 3	$ 6,800,000	FY 16
THULE AB	REPAIR AIRFIELD PAVEMENT, PH3	$ 9,325,000	FY 16
MACDILL AFB	Repair (SUS) Airfield Pavements	$ 6,900,000	FY 16
MACDILL AFB	RPR (SUS) Runway Pavements	$ 9,200,000	FY 16
JB ELMENDORF-RICHARDSON	REPAIR RUNWAY 06/24 CONCRETE REGROOVE	$ 8,200,000	FY 16
NORTHWEST GUAM AFB	Repair NWF North Runway, LZ	$ 5,000,000	FY 16

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Appendix D: Air Force Base Area Adjustment Factors

Table 8: Area Adjustment Factors (Fortier et al., 2015)

Air Force Base	Area Adjustment Factor	State	Closest RSMeans® Location
Altus	84.2	OK	Lawton
Andrews	91.2	MD	College Park
Barksdale	83.0	LA	Shreveport
Beale	108.7	CA	Sacramento
Cannon	87.1	NM	Clovis
Charleston	84.8	SC	Charleston
Columbus	79.7	MS	Tupelo
Creech	104.3	NV	Las Vegas
Davis-Monthan	86.5	AZ	Tucson
Dover	103.6	DE	Dover
Dyess	83.3	TX	Abilene
Edwards	106.3	CA	Bakersfield
Eglin	84.6	FL	Pensacola
Eielson	119.00	AK	Fairbanks
Ellsworth	82.6	SD	Rapid City
Elmendorf	118.7	AK	Anchorage
Fairchild	94.2	WA	Spokane
Grand Forks	80.4	ND	Grand Forks
Hill	85.9	UT	Ogden
Holloman	84.4	NM	Las Cruces
Hurlburt	84.6	FL	Pensacola
JBMDL	111.5	NJ	Trenton
Keesler	81.3	MS	Biloxi
Lackland	84.0	TX	San Antonio
Langley	86.1	VA	Newport News
Laughlin	84.4	TX	Del Rio
Little Rock	83.4	AR	Little Rock
Luke	73.8	AZ	Phoenix
MacDill	90.6	FL	Tampa
Maxwell	81.2	AL	Montgomery

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McChord	100.9	WA	Tacoma
McConnell	85.6	KS	Wichita
Minot	89.0	ND	Minot
Moody	82.3	GA	Valdosta
Mountain Home	90.7	ID	Boise
Nellis	104.3	NV	Las Vegas
Offutt	90.8	NE	Omaha
Patrick	87.2	FL	Orlando
Robins	83.0	GA	Macon
Scott	102.7	IL	St Louis MI
Seymour Johnson	80.3	NC	Raleigh
Shaw	80.6	SC	Columbia
Sheppard	82.8	TX	Wichita Falls
Tinker	85.2	OK	Oklahoma City
Travis	108.7	CA	Sacramento
Tyndall	81.7	FL	Panama City
Vance	82.9	OK	Enid
Vandenberg	106.0	CA	Santa Barbara
Whiteman	97.2	MO	Jefferson City
Wright-Patterson	92.1	OH	Dayton

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Appendix E: Air Force Recommended Treatments

Table 9: Air Force Recommended Treatment Cost Table

Air Force Recommended Treatment Cost Table						
Distress	Severity	Description	Code	Work Type	Work Unit	Work Cost
61	High	*BLOW-UP*	*SL-PC*	Slab Replacement - PCC	*SqFt*	$ 22.22
61	Low	*BLOW-UP*	*PA-PP*	Patching - PCC Partial Depth	*SqFt*	$ 11.18
61	Medium	*BLOW-UP*	*PA-PF*	Patching - PCC Full Depth	*SqFt*	$ 62.23
62	High	*CORNER BREAK*	*PA-PF*	Patching - PCC Full Depth	*SqFt*	$ 62.23
62	Medium	*CORNER BREAK*	*PA-PF*	Patching - PCC Full Depth	*SqFt*	$ 62.23
63	High	*LINEAR CR*	*PA-PP*	Patching - PCC Partial Depth	*SqFt*	$ 11.18
63	Medium	*LINEAR CR*	*CS-PC*	Crack Sealing - PCC	*Ft*	$ 4.05
64	High	*DURABIL. CR*	*SL-PC*	Slab Replacement - PCC	*SqFt*	$ 22.22
64	Medium	*DURABIL. CR*	*PA-PF*	Patching - PCC Full Depth	*SqFt*	$ 62.23
65	High	*JT SEAL DMG*	*JS-LC*	Joint Seal (Localized)	*Ft*	$ 3.38
66	High	*SMALL PATCH*	*PA-PP*	Patching - PCC Partial Depth	*SqFt*	$ 11.18
66	Medium	*SMALL PATCH*	*PA-PP*	Patching - PCC Partial Depth	*SqFt*	$ 11.18
67	High	*LARGE PATCH*	*PA-PF*	Patching - PCC Full Depth	*SqFt*	$ 62.23
67	Medium	*LARGE PATCH*	*PA-PP*	Patching - PCC Partial Depth	*SqFt*	$ 11.18
69	N/A	*PUMPING*	*UN-PC*	Undersealing - PCC	*Ft*	$ 3.18
70	High	*SCALING*	*SL-PC*	Slab Replacement - PCC	*SqFt*	$ 22.22
70	Medium	*SCALING*	*PA-PP*	Patching - PCC Partial Depth	*SqFt*	$ 11.18
71	High	*FAULTING*	*GR-PP*	Grinding (Localized)	*Ft*	$ 4.64
71	Medium	*FAULTING*	*GR-PP*	Grinding (Localized)	*Ft*	$ 4.64
72	High	*SHAT. SLAB*	*SL-PC*	Slab Replacement - PCC	*SqFt*	$ 22.22
72	Medium	*SHAT. SLAB*	*SL-PC*	Slab Replacement - PCC	*SqFt*	$ 22.22
74	High	*JOINT SPALL*	*PA-PP*	Patching - PCC Partial Depth	*SqFt*	$ 11.18
74	Medium	*JOINT SPALL*	*PA-PP*	Patching - PCC Partial Depth	*SqFt*	$ 11.18
75	High	*CORNER SPALL*	*PA-PP*	Patching - PCC Partial Depth	*SqFt*	$ 11.18
75	Medium	*CORNER SPALL*	*PA-PP*	Patching - PCC Partial Depth	*SqFt*	$ 11.18
76	Medium	*ASR*	*PA-PP*	Patching - PCC Partial Depth	*SqFt*	$ 11.18
76	High	*ASR*	*SL-PC*	Slab Replacement - PCC	*SqFt*	$ 22.22
62	Low	*CORNER BREAK*	*CS-PC*	Crack Sealing - PCC	*Ft*	$ 4.05
65	Medium	*JT SEAL DMG*	*JS-SI*	Joint Seal - Silicon	*Ft*	$ 3.38
74	Low	*JOINT SPALL*	*CS-PC*	Crack Sealing - PCC	*Ft*	$ 4.05
75	Low	*CORNER SPALL*	*CS-PC*	Crack Sealing - PCC	*Ft*	$ 4.05

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Appendix F: Summary Tables

Table 10: Condition Threshold Summary Metrics

Condition Threshold Summary Metrics				
Description	**Total Cost**	**Highest Priority Rank Treated**	**# Slabs Repaired**	**Percent of Slabs Repaired**
PCI < 70	$ 281,000,000	104	21800	11.8%
FOD > 20	$ 768,000,000	111	79600	42.9%
PCI Deduct > 10	$ 271,000,000	62	27200	14.7%

Table 11: Recommended Funding Approach Summary Metrics

Recommended Funding Approach Summary Metrics				
Description	**Total Cost**	**Highest Priority Rank Treated**	**# Slabs Repaired**	**Percent of Slabs Repaired**
PCI < 70 & PCI Deduct >10	$ 110,000,000	54	8990	4.8%
Jnt Seal Rpr (High/Med Sev Joint Seal Damage)	$ 11,500,000	N/A	36,800	19.8%
Jnt Seal Rpr (High Sev) & Slab Rep PCI Deduct >10	$ 177,000,000	65	40,400	21.8%
Jnt Seal Rpr (High Sev) & Section PCI <70	$ 285,000,000	104	35,000	18.9%
Jnt Seal Rpr (High/Med), PCI <70, PCI Deduct >10	$ 122,000,000	54	45,700	24.7%

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Table 12: Dover AFB and Columbus AFB Large Project Comparison Metrics

Base Project Comparison Metrics				
Description	**Total Cost**	**Highest Priority Rank Treated**	**# Slabs Repaired**	**Percent of Slabs Repaired**
Dover Funding Limit ($81.2M)	$ 1,510,000,000	All Corrected	18500	100%
$81,200,000 Ranked By Distress Priority	$ 80,600,000	31 - Linear Crack	6300	3.4%
$81,200,000 Ranked By Section PCI	$ 80,900,000	New PCI 36	6000	3.2%
Columbus Funding Limit ($12M)	$ 76,600,000	All Corrected	15300	100%
$12 Mil Ranked By Distress Priority	$ 12,000,000	104 - Corner Spall	2340	15.3%
$12 Mil Ranked By Section PCI	$ 11,900,000	New PCI 85	1750	11.4%

Table 13: Air Force Recommended M&R Treatment Summary Metrics

AF Recommended M&R Treatments				
Description	**Total Cost**	**Highest Priority Rank Treated**	**# Slabs Repaired**	**Percent of Slabs Repaired**
PCI <70	$ 11,000,000	104	21800	11.8%
PCI Deduct > 10	$ 12,700,000	62	27200	14.7%
PCI Deduct >10 & PCI <70	$ 9,550,000	54	8990	4.8%

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Appendix G: Air Force Recommended Findings Table

Table 14: Air Force Recommended Findings

AF Recommended Findings				
Distress Type	**Severity**	**PCI Deduct**	**Distress Priority Ranking**	**AF Recommended Treatment**
Linear Crack	High	*82.1*	3	Patching - Partial Depth
Linear Crack	Medium	56.5	8	Crack Sealing
Shattered Slab	Low	53.7	9	No Localized M&R
ASR	Low	21.8	30	No Localized M&R
Linear Crack	Low	21.7	31	No Localized M&R
Durability Crack	Low	20.2	35	No Localized M&R

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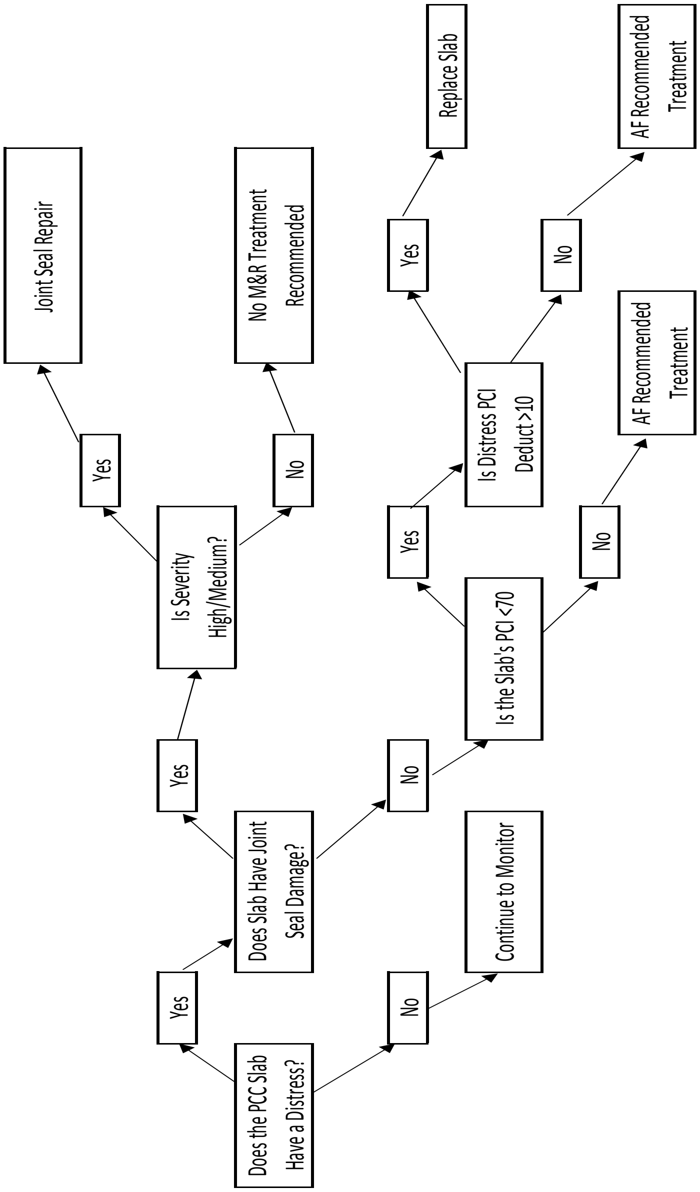
Appendix H: Recommended Treatment Decision Tree



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14. ABSTRACT

The Air Force is facing the challenge to preserve the current inventory of 154 million square yards of paved airfield assets while at the same time reducing the budget by $36.2 billion between fiscal years 2015-2019. This research sought to determine a selective maintenance and rehabilitation treatment approach that allocates resources efficiently to preserve the degrading pavement assets in the financially constrained environment. Air Force pavement inspection reports from the past five years provided 4289 observed pavement distress data points for this research. The data was inputted into the pavement management software, PAVER™, to calculate the Pavement Condition Index (PCI) deduct values for every pavement distress combinations. A pavement distress prioritization list was created from the 111 PCI deduct value calculations to rank the impact that different distresses have on the condition of pavement systems. The analysis led to the recommended selective maintenance and rehabilitation treatment approach of treating all medium and high severity joint seal damage with joint seal repair, repairing all pavement slabs with slab replacement that had a PCI less than 70 and with a PCI deduct greater than 10, and using all remaining resources on the Air Force recommended treatments. The recommended approach minimizes the potential of Foreign Object Damage, uses corrective measures in the form of slab replacement to repair the worst conditioned and highest priority slabs, and reduces further pavement degradation with the Air Force recommended treatments.

15. SUBJECT TERMS
Pavement Condition Index, Selective Slab Replacement, Maintenance and Rehabilitation, Prioritization, Portland Cement Concrete

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