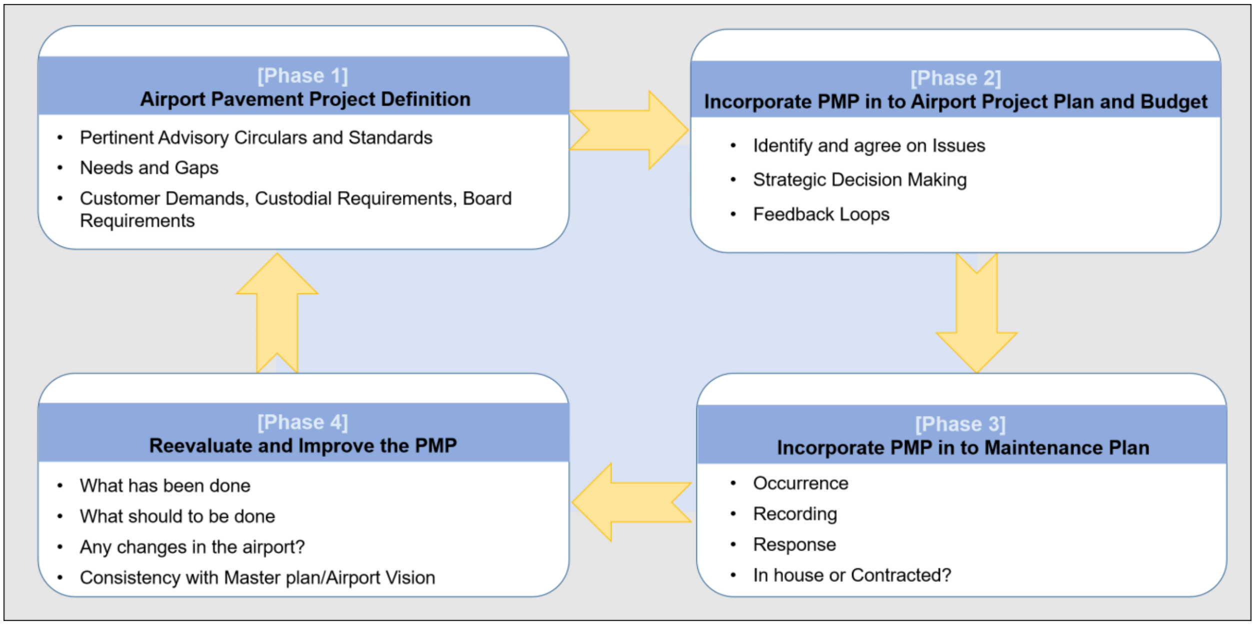
2021-2022 ACRP UNIVERSITY DESIGN COMPETITION

A Systematic Decision-Making Approach for Developing and Maintaining a Plan for Airport Pavement

(January 2022 - April 2022)



Design Challenge: Airport Operations and Maintenance: Challenge A

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Executive Summary

This proposal focuses on **Airport Operations and Maintenance Challenge A: Exploring new methods for design and maintenance of pavement surfaces.** There is an overwhelming amount of regulations, standards, and recommended practices governing airport pavement management, monitoring, and maintenance. Airport pavement can vary in design and materials, so individual airports require a customized Pavement Management Plan (PMP). The Federal Aviation Administration (FAA) *Advisory Circular 150/5380-7B* recommends that airports establish a PMP, and is required to receive Airport Improvement Plan funding (FAA, 2014). A PMP can extend the life of airport pavement by a third of its original design, and save costs in maintenance and repair (WHPacific, 2012). However, due to the initial costs and time required to develop a PMP, many airports have yet to establish a comprehensive or sustainable PMP.

This proposal introduces a simplified and systematic decision-making process to assist airport personnel with formulating and maintaining a design for pavement management, monitoring and maintenance. A review of applicable literature as well as interactions with industry experts aided the creation of this design. This final design includes four phases: airport pavement project definition, incorporation into airport project plan and budgeting, incorporation into airport maintenance plan, and then reevaluate and improve the plan. This process includes continuous evaluations via single and double feedback loops to increase the maintainability, sustainability, and longevity of a PMP.

A cost benefit analysis that considers the research and development, phases of implementation, and direct benefits to airports from maintaining a PMP over the span of 10 years yielded a benefit to cost ratio of 1.57.

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Problem Statement and Background

Safety is of paramount concern in all aspects of aviation, and applies to the **Airport Operations and Maintenance Challenge A: Exploring new methods for design and maintenance of pavement surfaces.** The continued upkeep of airport movement areas is crucial to maintaining safe operations. In the International Civil Aviation Organization *Annex 14*, “movement areas” are defined as the parts of an airport used for take-off, landing, taxiing, and moving aircraft (ICAO, 1990). Maintaining airport pavement in these movement areas can reduce the possibility of airframe, engine, or personal damage.

The Air Transport Action Group (ATAG) forecasts in the *Waypoint 2050* report that the amount of passenger traffic will double by year 2040 - and continue to increase - even after taking the COVID 19 pandemic into account (ATAG, 2021). In addition to stresses of taxi traffic and routine high-impact forces from frequent Landing-Take Off (LTO) cycles, airports may experience potential climate change effects such as fluctuating hot and cold temperatures and increased precipitation intensity from extreme weather patterns (Gudipudi et al., 2017). These effects add to the combined stresses imposed on current airport surfaces and associated maintenance and repair strategies.

The Federal Aviation Administration (FAA) *Advisory Circular (AC) 150/5380-7B* recommends that airports establish a Pavement Management Program (PMP). The implementation and continuous support of a PMP can extend the life of airport pavement by an average of ⅓ of its original design, as well as save substantial maintenance/repair costs in the long term (WHPacific, 2012). However, establishing a PMP can be costly and time consuming.

There is an overwhelming amount of regulations, recommended practices, standards, and methods governing airport pavement monitoring and maintenance. Different pavement types require tailored solutions. Airports often have a mixture of pavement materials (asphalt, concrete) and/or design (grooves, anti-skid, smooth) between taxiways, aprons, runways, and ramps. Based on industry interactions with various airport directors, airport construction personnel, and contractors, this influx of information makes the process of establishing a systematic and organized PMP difficult.

The problem is that many airports face a growing gap in proactive maintenance and inspection with changing environmental factors and high-volume predictions. Once established, pavement management plans may be useful only when fully incorporated into existing airport plans, maintenance operations, and airport budget.

In order to sustain predicted volume, capacity, safety, and reliability at airports, methods for airport pavement inspection, maintenance, and rehabilitation must be established.

The purpose of this proposal is to introduce a simplified and systematic decision-making process to assist airport personnel with formulating and maintaining a design for pavement management, monitoring and maintenance.

This proposed process increases accessibility and understanding for smaller airports or airports that have yet to implement a systematic and holistic plan for pavement management.

Summary of Literature Review

This literature review compiles existing methods, standards, and regulations related to airport pavement integrity and management of movement areas. This includes a review of FAA regulations, ASTM standards, and aviation/airport operations to assess trends and methods for pavement inspection, monitoring, and maintenance.

1. Regulations and Standards

This section of the literature review lists current recommendations and standards regarding pavement maintenance and management that organizations such as the FAA and ASTM have put forth. In addition, ACs and standards that may prove helpful to understand the scope of pavement management, monitoring, and maintenance are included.

1.1. Federal Aviation Administration (FAA)

The FAA requires airport operators to be certified under 14 Code of Federal Regulations Part 139. To obtain a certificate, an airport must maintain the movement area to the conditions outlined in the regulation (Aeronautics and Space, 2004). According to the Operational Life of Airport Pavements DOT/FAA/AR-04/46, the FAA provides funding for runway repair for eligible airports per the Airport Improvement Plan (AIP) (Garg, 2014). More than half of all AIP funds are used toward re-pavement and repair (FAA, 2021b). According to the FAA AIP Handbook, the useful life of pavement averages 20 years (FAA, 2019). Table 1 shows project life spans per the AIP for funding eligibility.

Table 1
Minimum Useful Life (FAA AIP Handbook Chapter 3, Table 3-7)

Project Type	Useful Life
All construction projects	20 years
Pavement rehabilitation (not reconstruction, which is 20 years)	10 years
Asphalt seal coat, slurry seal, and joint sealing	3 years
Concrete joint replacement	7 years

Note: Table 1 is a derived from Tables 3-7of the Airport Improvement Program Handbook. Federal Aviation Administration. (2019). Order 5100.38D. Airport Improvement Program Handbook. Retrieved from https://www.faa.gov/airports/aip/aip_handbook/media/AIP-Handbook-Order-5100-38D-Chg1.pdf

In 2011, the FAA launched PAVEAIR, a web-based public airport pavement management system that can assist airports with managing pavement (FAA, 2022). The group learned from interactions with FAA personnel that there are currently, 557 confirmed accounts listed with an airport code and 2,323 accounts without an airport code.

1.1.1. Airport Pavement Design and Evaluation (AC 150/5320-6G). This document provides general knowledge about airport pavement design, soil analysis, pavement maintenance, structural evaluation, Non-Destructive Testing (NDT), and other general recommendations regarding the construction, monitoring, and maintenance of airport pavements. This AC is applicable and mandatory for airports receiving AIP funding. Explanations of auxiliary components of pavement (such as drainage), and some basic practices of FAA approved methods for pavement monitoring and maintenance are also provided (FAA, 2021a).

1.1.2. Measurement, Construction, and Maintenance of Skid Resistant Airport Pavement Surfaces (AC 150/5320-12C). This document focuses on skid-resistant pavement surfaces. This AC provides information relating to grooved pavement, Porous Friction Course (PFC) runways, and other anti-skid finishes. The main method of pavement evaluation mentioned in this AC is with Continuous Friction Measuring Equipment (CFME), which determines the friction coefficient of pavement. This source also provides standard depth measurements for comparison. This AC is not mandatory for airports receiving AIP funding (FAA, 1997).

1.1.3. Airfield Pavement Surface Evaluation and Rating Manuals (AC 150/5320-17A). This AC provides manuals relating to the evaluation and rating of surface pavement, with two appendices for asphalt and concrete. The provided manuals specify ratings between one through five. These ratings, however, are based on visual inspection criteria such as surface deformation, cracking, and patching - with each manual tailored towards the specific defects found in concrete or asphalt. Visual references of these defects are provided as well. Each manual also provides a numbered rating. While advice on determining that rating is given, it is up to the individual inspector's discretion. While not mandatory for airports receiving AIP funding, the manuals provide valuable information for visual inspections of pavement (FAA, 2014a).

1.1.4. Standardized Method of Reporting Airport Pavement Strength - Pavement Classification Number (PCN) (AC 150/5335-5C). Referencing ICAO methods, this document advises a standard for classifying pavement strength, Pavement Classification Number (PCN), similar to ASTM Pavement Condition Indexes (PCI) or other pavement rating systems. This AC is applicable and mandatory to airports receiving AIP funding. PCN may also be referred to as Pavement Condition Rating (PCR). This document also includes a method for classifying aircraft, called the Aircraft Classification Number (ACN). The ACN and PCN are used in conjunction to determine if an aircraft can operate over a given stretch of pavement safely. Methods for determining ACN or PCN as well as data recording methods are also provided (FAA, 2014b).

1.1.5. Standard Specifications for Construction of Airports (AC 150/5370-10H). This advisory circular covers the construction of airports. Required for AIP funding, this document describes different construction requirements ranging from drainage to light fixtures. However, the relevant portion for this proposal are sections regarding pavement and surface treatments. Compliance with this AC is required to receive funding from the FAA (FAA, 2018).

1.1.6. Use of Nondestructive Testing in the Evaluation of Airport Pavements (AC 150/5370-11B). Current and accepted methods of Nondestructive Testing (NDT) for airport pavement inspection are listed here. This AC is applicable and mandatory for airports receiving AIP funding. This document includes approved equipment to measure deflection, vibration, and impulse of airport pavement. While the use of NDT can assist in inspection and assessment of pavement, this AC also clarifies that there is a limit to its operation. Other methods such as visual inspection should be used in conjunction. NDT equipment requires calibration and skilled interpretation, limiting its use to qualified personnel. This AC also references the use of PCI to record pavement condition data (FAA, 2011).

1.1.7. Guidelines and Procedures for Maintenance of Airport Pavements (AC 150/5380-6C). This document lists maintenance approaches in response to defects in pavement. In the context of PMPs and NDT, this AC describes methods for inspection and repair procedures. Methods for repair of rigid and flexible pavements are included as well as pertinent ASTM standards for repair material requirements (e.g. ASTM D977 for cold-applied sealants, etc.). For airports receiving AIP funding, all pavement will have to adhere to AC 150/5370-10, Standards for Specifying Construction of Airports (FAA, 2014c).

1.1.8. Pavement Management Programs (AC 150/5380-7B). This AC describes the concept of airport PMPs, applicable and mandatory to airports receiving funding through AIP. This AC claims that the upkeep and maintenance to keep pavement in “good” condition is four to five times less costly than repair or rehabilitation for pavement in “poor” condition, while extending the pavement’s useful life. Pertinent components of a PMP are listed here as well, some examples being a systematic means for collecting/storing information, procedures for predicting pavement conditions, and procedures for determining and allocating budget for a PMP. While this AC is a starting point, as shown by other ACs in this literature review there are several different proposed ‘standards’ that an airport will need to choose from in order to establish a successful PMP. This document, in addition to established and practiced PMPs that are airport specific, influence the proposed design illustrated later in this paper (FAA, 2014d).

1.1.9. Guidelines and Procedures for Measuring Airfield Pavement Roughness (AC 150/5380-9). Acceptable and unacceptable ranges for pavement roughness can be found within this AC. The use of this AC is applicable and mandatory for airports receiving AIP funding. This document lists the different types of roughness deformities that may be found, and describes the "Boeing Bump" method of roughness identification in detail (the Boeing Bump Index, BBI) (FAA, 2009).

1.2. ASTM Standards and Recommended Practices

Along with ACs provided by the FAA, airport personnel can also reference ASTM standards for advice on how to monitor and maintain their movement surfaces.

1.2.1. ASTM Standard Guide for Pavement Management Implementation (ASTM E1889-97). Per the ASTM, pavement management is defined as the process of "providing and maintaining pavements… generated from a pavement management system (PMS)... [and is] considered complete when pavement management is a routine part of the management process…" (American Society for Testing and Materials, 2019, p. 1). The decision-making process in this standard provides details to assist airport management in fully incorporating pavement management into the scope of the full airport plan. This procedure includes steps such as identifying needs for a pavement plan, gathering information, deciding on action, committing to resources, documenting results, and revising and evaluating goals (ASTM, 2019). The procedure described has influenced this project's proposed design.

1.2.2. ASTM Standard Test Method for Non-Repetitive (ASTM D1196M-21) and Repetitive (ASTM D1195M-21) Static Plate Tests of Soils and Flexible Pavement Components for Use in Evaluation and Design of Airport and Highway Pavements. These documents describe standard procedures and tolerances when determining the strength of pavement in relation to subsurface materials. These documents are listed together because the main difference between the two is whether or not the test is conducted repetitively or non-repetitively. The tests are conducted with a hydraulic press and rigid plates, with downward pressure in increasing increments (ASTM, 2021a; ASTM, 2021b). This source is an example of testing or monitoring methods that are used in multiple industries.

1.2.3. ASTM Pavement Condition Index (ASTM D5340-20). A Pavement Condition Index, or PCI, is another method of classifying pavement. ASTM defines PCI as “a numerical rating of the pavement condition that ranges from 0 to 100, with 0 being the worst possible condition and 100 being the best possible condition” (ASTM, 2020). During our research, a 10 year analysis of a PMP in Oregon organized by the Oregon Department of Aviation utilized PCI as a method of tracking and classifying pavement wear over time, and allowed for predictive maintenance that prolonged the life of airport movement areas (WHPacific, 2012).

2. Current State of Monitoring and Maintenance

The pavement design for an airport depends on multiple factors: funding, operational constraints, material availability, cost and frequency of maintenance, environmental concerns, future airport expansion plans, and anticipated changes in traffic (FAA, 2021). Recent studies on airport pavement failure modes have shown that airport pavement lifecycle can decrease to around one quarter of its original state, including breaks and rutting, much earlier than anticipated (Daniel et al., 2014; Mills et al., 2009; Mndawe et al., 2013). This section describes current methods of pavement monitoring and management.

2.1. Monitoring

Through one of the group's industry contacts, it was learned that the most common method for monitoring pavement condition is through a visual inspection. While sensor technology such as Ground Penetrating Radar can assist in subsurface detection, it is typically only implemented in specific situations where the need can be justified.

In the Pavement Management Implementation symposium of ASTM International, Murrell et al. (1991) described that pavement management was often left to a designated engineer, who would rely on visual inspection, repair in the same day, and plan the budget for pavement rehabilitation (Murrell et al., 1991). However, pavement management took a quick change as air traffic began to increase and larger aircraft were taking off and landing on the runways (Murrell et al., 1991). In response, airports began to use Integrated Airport Pavement Management System (IAPMS) along with thematic and Geographic Information System (GIS) mapping. This software enabled airport pavement data to be condensed into an easily accessible database (Murrell et al., 1991). Eckrose and Reynolds (1991) also published in the ASTM International Pavement Management Implementation symposium regarding the development of pavement management plans in Indiana airports (Eckrose & Reynolds, 1991). These plans, incorporated in phases, heavily used PCIs and incorporated decision-making tools and metrics to allow for airports to sustain their pavement management plans. The comprehensive guide to establishing a standard pavement management plan statewide allowed for Indiana airports to perform constant and practical inspections and rehabilitations. In addition, this case study emphasizes the need for pavement management plans to be heavily customizable for a given airport regarding geographic locations and traffic levels (Eckrose & Reynolds, 1991).

Several methods recommended in FAA ACs or by the ASTM standards are available to airport personnel for data recording. These methods include Pavement Condition Indexes, Pavement Classification Numbers, visual pavement ratings, surface roughness inspections, friction testing, and load testing. Some methods of monitoring, like PCI, PCN, and visual pavement ratings, can be comprehensive to an entire airport. Other methods, such as NDT methods like friction and load testing, may be specific to parts of an airport where stresses are higher, such as the middle of a runway where takeoff and landing occurs.

2.2. Maintenance

When dealing with maintenance, possible defects differ with the material and design of pavement. Those properties should be considered when conducting an inspection. Asphalt mix and cement concrete are the two most utilized materials for airport movement surfaces (FAA, 2014). Pavement may be designed as skid resistant/anti-skid with physical changes such as grooves. Maintenance performed also depends on whether the pavement is rigid or flexible (FAA, 2014). Proper repair method must be selected with adequate consideration. Per *AC 150/5380-6C*, common methods of pavement repair include crack repair, joint sealing, depth repair, corner breaks, partial and full slab replacement, spall repairs, and patching (FAA, 2014).

3. ACRP Project Reports

This section describes further reports that were analyzed from existing ACRP studies, many of which are ongoing, including summaries of what the group learned from them. The abbreviation form of NASEM (National Academies of Sciences, Engineering, and Medicine) will be used for in-text citations. Table 2 summarizes findings from these reports.

Table 2

ACRP research report regarding pavement

Project Number	Project Title	Findings
ACRP 02-64 (NASEM, 2017)	Guidance for Usage of Permeable Pavement at Airports	The need for sustainability and low-impact development pavement including permeable pavement Stated difficulty to adapt leading tech. different from conventional ones due to unique feature of airports
ACRP 09-01 (NASEM, 2010)	Guidelines for the Collection and Use of Geospatially Referenced Data for Airfield Pavement Management	Pavement Management System including data collection is essential for effective management of airfield pavement Difference in definition and format make it difficult for utilizing them
ACRP 09-11 (NASEM, 2016)	Pavement Maintenance Guidelines for General Aviation Airport Management	Providing the standard guide for pavement management, which is an effective preventative maintenance, is vital due to GA's typical problem of a lack of competence.
ACRP 09-17 (NASEM, 2019a)	Collecting, Applying, and Maintaining Pavement Condition Data at Airports	Provides methods to use in the collection, interpretation, application, and maintenance of pavement condition data, which differ from airports to airports
ACRP 09-18 (NASEM, 2021)	Rapid Airfield Concrete Pavement Slab Replacement and Patching Guidance	Introduced the recent advancements in materials and procedures for rapid repair of airfield concrete pavement in order to minimize runway closure time
ACRP Synthesis 11-03/Topic S09-02 (NASEM, 2011)	Common Airport Pavement Maintenance Practices	Synthesize a wealth of information on pavement maintenance; yet, it appears that current technology and practices need to be updated.
ACRP 02-78 (NASEM, 2019b)	Climate Resilience and Benefit Cost Analysis	Stating the increasing need of dealing with climate change as an airport operator

Industry Interaction

To gain a more practical understanding of the current state of pavement management, monitoring, and maintenance, industry experts of different disciplines were interviewed. Contacts included airport operators, academic experts, FAA personnel, and civil engineering personnel. Each expert was crucial to the development of this project, as the group was able to discern professional perspectives of pavement management beyond the available literature. The group was able to discover real-world concerns and limitations of pavement approaches currently used in airport operations. Figure 1 shows example questions asked to experts.

Figure 1

Example Questions Directed to Expert Contacts

Q1	What are the current pavement management practices and budgeting requirements?
Q2	What challenges do airports face when implementing a PMP?
Q3	What standards and regulations are most referenced?
Q4	What are the most common pavement maintenance procedures?

The group learned from airport construction experts that it is becoming increasingly important to locate and correct pavement defects, particularly in environments with fluctuating climates. Pavement inspection is still largely dependent on eye examination. Core sampling, another common practice in pavement monitoring, is problematic as it is a destructive method and different results can be obtained on the same pavement using differing methods. From the information provided, the group concluded that determining when and how to perform maintenance can be challenging, and often relies on the opinion of contracted experts.

Based on this concern, the group's initial project focus was to determine a method to apply cutting-edge technology such as LIDAR or drones to detect the cracks on airport pavement in a timely and accurate manner. However, from discussions about sensing technology with academic experts, civil engineering experts, and airport directors, the group concluded that the pavement dilemma should be handled from a procedural standpoint rather than the introduction of new and expensive technologies. The group understood that airports, especially smaller airports, may have difficulties starting development of a PMP due to costs and time. The group also gathered that a standard, "one-size-fits-all" PMP would not be feasible, due to the different environmental conditions and pavement designs between airports. Therefore, the focus for this project shifted to a systematic decision-making approach to aid all airports in the development of a customized PMP.

Civil engineering experts provided resources on how PCI and PMP can increase airport pavement life by 100% through empirical studies. From this information, the group was able to infer that despite the suggested efficacy of PMPs as well as FAA and state DOT recommendations, many airports have yet to establish their own PMPs. Small airports, in particular, can lack the qualified personnel, startup budget, and resources necessary.

The group learned from airport operators that cost effectiveness can be as important as safety in order to maintain sustainability. The group gathered that it is crucial to implement a plan that is effective and conservative while minimizing disruptions to operations and extending pavement life. From one particular discussion with an expert, the group learned how costly it can be for an airport to shut down a runway. One of the country's busiest airports, JFK, allegedly charged a contractor around $300,000 per hour for a pavement project delay resulting in operational disruptions a few years ago.

The group also learned about the current and future states of airport pavement, pavement management software available for airport use, the properties and failure modes of concrete and asphalt, and the future scope of pavement from a sustainability perspective (such as the possibility of recycled material to make pavement). The group understood that airport pavements need to be specifically designed in accordance with local environmental and traffic conditions, and greener technologies are expected in order to enforce airport sustainability. Throughout each discussion with our expert contacts, the team understood that the aviation industry is working together to promote airport sustainability and incorporate greener technologies. Table 3 provides an overview of expert contacted by the group.

Table 3

Industry interaction contacts

Affiliation	Title	Name
Academia		
Purdue University, School of Aviation and Transportation Technology	Professor	Dr. Stewart Schreckengast
	Professor	Dr. Damon Lercel
	Professor	Dr. Joseph Hupy
Airports		
Corpus Christi International Airport	Deputy Aviation Director	Tyler Miller
	Airport Development & Construction Manager	Victor Gonzalez
West Virginia International Yeager Airport	Airport Director & CEO	Nick Keller
Civil Engineering Organizations		
WSP	Vice President and National Aviation Planning Manager	John van Woensel
Garver	Aviation Project Manager	Derek Mayo
	Maintenance Program Leader	Aaron Smith
Airport Design Consultants, INC.	Practice Manager	Alan Peljovich
FAA		
FAA Technical Center	Researcher	Dr. Navneet Garg

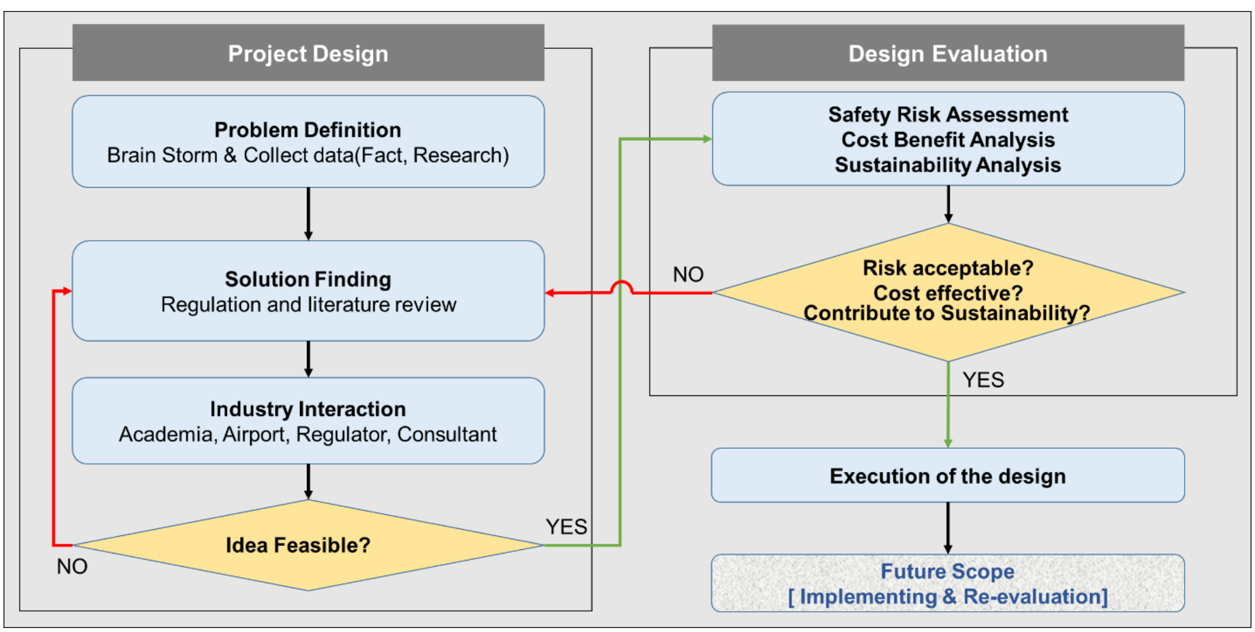
Problem Solving Approach

This proposal underwent several redirections during its development. The group's approach for determining the best course for this project is depicted in Figure 2. The group began by defining a problem, such as detecting defects in airport pavement. Then, solutions were discovered through a literature review and meetings with industry experts. The initial idea for this proposal involved introducing sensor technologies for pavement monitoring, however upon review of the literature and discussions with industry personnel, it was determined that this solution was not feasible due to the costs, skills, and accuracy required for most sensing equipment. Therefore, the group had to brainstorm for different solutions, considering what was learned previously from industry experts' practical perspectives. Eventually, the group determined that a procedural approach to developing, maintaining, and sustaining a PMP would be the most feasible solution to detect defects in airport pavement. The project's focus shifted towards assisting airports in developing a systematic decision-making approach to guide airports in the development or refinement of a PMP.

Once the design of this proposal had been decided, the group was able to analyze the quality of the design. Safety-risk, cost-benefit, and sustainability assessments were performed. The last few steps are outside of the scope of this paper, and are up to an airport to complete. This includes executing the design, and adjusting for future changes. The future scope of this project may include changes to ACs, new pavement materials (such as recycled pavements), or new technologies that aid in an airport's PMP.

Figure 2

Problem Solving Flow Chart

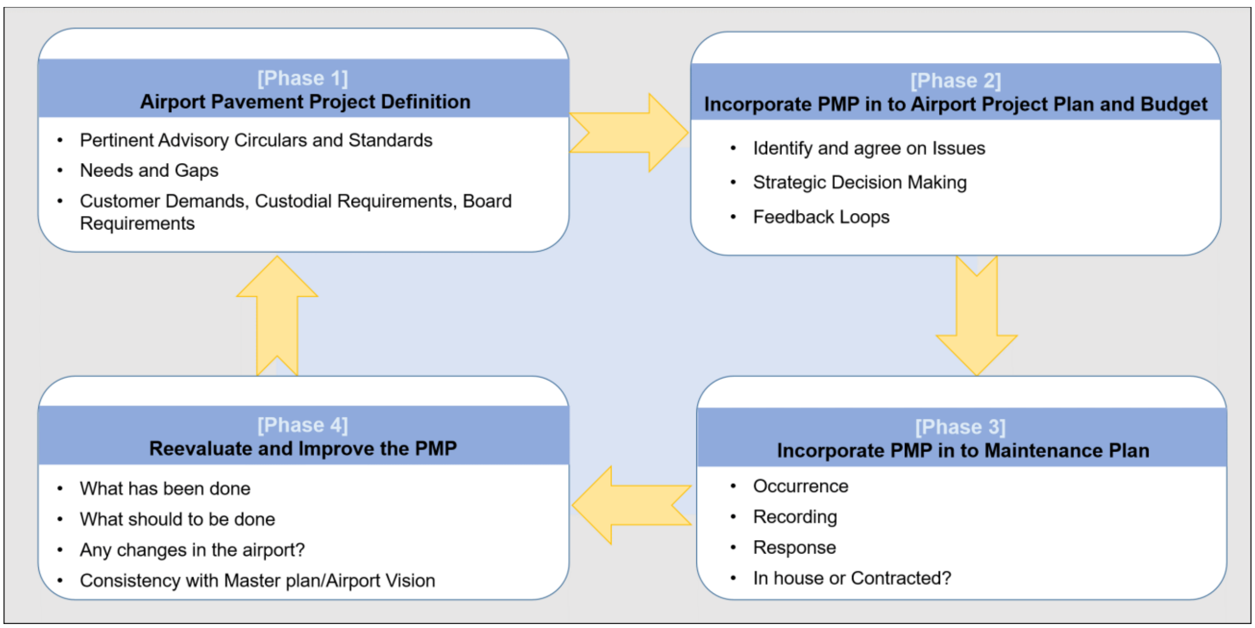


Project Design and Principle

The design of this project is a systematic decision-making process to aid airports in managing and maintaining an updated PMP. This process includes four phases – airport pavement project definition, incorporation into airport plan and budgeting, incorporation into airport maintenance plan, and reevaluation and improvement of the plan. Figure 3 provides an overview of the process.

Figure 3

Flow Model of Proposed Design for Pavement Management Plan Decision Process



Phase 1: Airport Pavement Project Definition

In order to establish a plan for pavement management, the scope of an airport's pavement qualities (material, design) as well as pertinent ACs and standards should be identified. This first phase should be used to understand the requirements and desires from customers, custodial parties, and relevant boards, such as impressions derived about the airport based on asset upkeep. Phase 1 is implemented in three steps.

Step 1: Identify Pertinent Regulations and Standards

Applicable ACs and standards for a given airport pavement design should be identified, if not already. Standards may include recommendations through an organization such as ASTM, and/or an airport's own established standards. As mentioned in the literature review, different ACs and standards apply to different pavement materials, such as asphalt or concrete. This is also true depending on the design of the pavement, such as anti-skid or smooth. FAA requires airports to adhere to relevant ACs for AIP funding assistance regarding pavement rehabilitation or repair. Table 4 lists current pavement focused ACs and ASTM standards.

Table 4

Summarized ACs and Standards

Relevancy	Document Number	Document Title
Concrete	AC 150/5320-17A	Airfield Pavement Surface Evaluation and Rating Manuals
Asphalt	AC 150/5320-17A	Airfield Pavement Surface Evaluation and Rating Manuals
Anti-Skid Pavement	AC 150/5320-12C	Measurement, Construction, and Maintenance of Skid Resistant Airport Pavement Surfaces
Monitoring	AC 150/5335-5C	Standardized Method of Reporting Airport Pavement Strength - Pavement Classification Number
	AC 150/5370-11B	Use of Nondestructive Testing in the Evaluation of Airport Pavements
	AC 150/5380-9	Guidelines and Procedures for Measuring Airfield Pavement Roughness
	AC 150/5320-17A	Airfield Pavement Surface Evaluation and Rating Manuals
	ASTM D1196M-21	ASTM Standard Test Method for Non-Repetitive Static Plate Tests of Soils and Flexible Pavement Components for Use in Evaluation and Design of Airport and Highway Pavements
	ASTM D1195M-21	ASTM Standard Test Method for Repetitive Static Plate Tests of Soils and Flexible Pavement Components for Use in Evaluation and Design of Airport and Highway Pavements
	ASTM D5340-20	ASTM Pavement Condition Index
Required for AIP Funding	AC 150/5320-6G	Airport Pavement Design and Evaluation
	AC 150/5335-5C	Standardized Method of Reporting Airport Pavement Strength - Pavement Classification Number
	AC 150/5370-11B	Use of Nondestructive Testing in the Evaluation of Airport Pavements
	AC 150/5370-10H	Standard Specifications for Construction of Airports
	AC 150/5380-7B	Pavement Management Programs
	AC 150/5380-9	Guidelines and Procedures for Measuring Airfield Pavement Roughness

Step 2: Determine a Monitoring Method

In Table 4, there are seven items used to monitor pavement, e.g. PCN, PCI, or visual rating. A given airport may choose to monitor their pavement by using several methods in tandem. Once an airport has compiled pertinent regulatory and standard information, a decision can be made regarding the best-fit in terms of monitoring methods. This stage can also be used to establish a reporting and recording software, such as PAVEAIR, to assist in tracking the condition of pavement over time. By recording and tracking pavement over time, maintenance personnel will be able to perform predictive maintenance.

Step 3: Account for Customer Demands, Custodial Responsibilities, and Board Requirements

In addition to regulations and monitoring, airports should remain community conscientious. In doing so, the airport should be aware of airlines feedback regarding the overall quality of the airport. More importantly, the airport should recognize their own custodial obligations to maintain their airport in quality condition. Consider feedback from relevant aviation boards, for example, who may be in charge of dispersing funds. By showing good custodianship over an airport's structural assets, goodwill can be formed between these parties in pursuit of continued good standing for funding opportunities.

Phase 2: Incorporate PMP in to Airport Plan & Budget

Phase 2 describes a systemic decision-making process for management and implementation of an airport's pavement management plan with the intent of continued development and sustainability. The design of Phase 2 is based on the decision-making process in *Cost Management: A Strategic Emphasis* (Blocher et al., 2022), and includes additions to this process from Dr. Mary Johnson's lecture slides from the Purdue University course AT52400, Managerial Economic Decision-Making. Phase 2 is implemented in seven steps.

Step 1: Identify and agree on projects for the airport (pavement improvement).

Before implementing the pavement management plan, a meeting should be held including all leading personnel who will be involved with pavement management. This may range from airport directors/CEOs, accountants, construction managers, contractors (if applicable) for pavement rehabilitation/repair, and personnel assigned with runway inspection and/or maintenance. In this meeting, involved individuals should be able to reach a consensus regarding the needs and requirements of pavement management. This includes methods of monitoring and recording pavement condition, PCI or visual ratings, or recording software such as PAVEAIR.

Step 2: Identify strategic issues, identify which pavement projects are co-dependent, strategize and plan/prioritize.

Once a consensus has been reached regarding the needs and requirements for the airport's pavement management plan, procedures for maintenance should be identified. Now is the time for the airport to decide what maintenance possibilities are available in response to pavement defects. This is where input from either contractors, construction managers, and/or pavement maintenance personnel will be crucial. With these resources, a database of possible solutions can be developed for quick reference when a defect is discovered during an inspection or predicted based on previous monitoring data.

During this phase, the involved personnel can establish which maintenance items or defects are co-dependent or independent. Consider which items can be accomplished at the same time or in tandem and which items need to be completed sequentially? What circumstances will be deemed a high or low priority? What maintenance solutions would be available for a given situation? By establishing an order of operations for maintenance procedures, a halt in operations can be reduced as much as possible.

Step 3: Identify Alternate Methods of Action

Upon compiling all possible methods of maintenance and establishing an order of operations and priority levels, consider the components that will be necessary for each given action. For instance, how many employees or labor hours will be required? What kind of tooling or equipment will be necessary? What materials will be used?

Step 4: Perform an Analysis on Alternate Actions

Next, analyze the different methods identified in Step 3. First, establish the deciding factors, e.g. which course of action is most beneficial in terms of maintenance? Which is the most cost effective? Which is most practical and feasible for the airport's operations? Then, sort the alternate methods of maintenance in terms of the chosen deciding factors from most desirable to least. In addition, this stage can also be used for a cost analysis that allows for the pavement management plan to be implemented into the overall airport plan and budget.

Step 5: Choose and Implement Desired Action

The desired maintenance response items should now be identified. These practices can be reflected in a database, so that once it is deemed time for maintenance to be performed on pavement solutions are available for quick reference. Once this is established, the pavement management plan (monitoring, reporting, recording, and maintenance) can be implemented into routine airport operations.

Step 6: Evaluate Ongoing Effectiveness of Implemented Action

This stage of the decision-making process is used for single loop feedback analyses – are the chosen maintenance strategies effective? Implement the system as a trial run with maintenance and inspection personnel over three months. Over this time, assess the actual costs and benefits of the chosen system and compare with the predicted costs and benefits. Ask if movement area surfaces being kept in operable and adequate condition? Has down time in operations and the frequency of maintenance been reduced? Is maintenance able to be performed quickly, satisfactorily, and efficiently? Take note and record the inefficiencies and gaps found in the pavement management process.

Step 7: Re-Evaluate Solution

Now, step back and **perform a double loop analysis** by looking at Steps 1-6 in Phase 2. Is the current system the best way to operate? Is the chosen system sustainable? Address the feedback from the previous single loop analysis. Take time to reform the system if necessary, and complete any further trial runs needed. Revisions may include changing the method of monitoring, recording, or responding via maintenance procedures. These revisions may also involve systemic changes, such as chain of reporting or roles and responsibilities, or changes in supply chain such as materials and equipment sourcing.

Phase 3: Implement PMP in to Airport Maintenance Plan

In this phase, the system has completed all trial runs and is ready for integration into the airport management plan. This is done in three steps.

Step 1: Occurrence

Determine how often monitoring and recording will occur. This may be during routine runway inspections or at designated down periods. Will monitoring occur as a daily inspection? Establish what will be seen as weekly, quarterly and yearly procedures. Perhaps daily monitoring will be utilized for recording and preventative maintenance analysis, while weekly or quarterly analyses will be used for in-depth inspections, and yearly may be established for routine testing via nondestructive methods.

Step 2: Recording

As it has been determined and tested in phase 2 which method of recording will be utilized, it can be fully integrated into maintenance systems. Training may be required for all personnel utilizing the system. Ensure all personnel are aware of the standard practices and strategies needed for recording data timely and accurately.

Step 3: Response

Regarding the maintenance response, ensure personnel are aware of what priority levels require immediate action and what priority levels can be delayed (and for how long). If utilizing in-house employees, ensure maintenance personnel are properly trained to respond adequately to pavement defects. If an unforeseen defect arises in the pavement, ensure that all personnel understand the procedure for acquiring contracted assistance.

Phase 4: Reevaluate and Improve the PMP

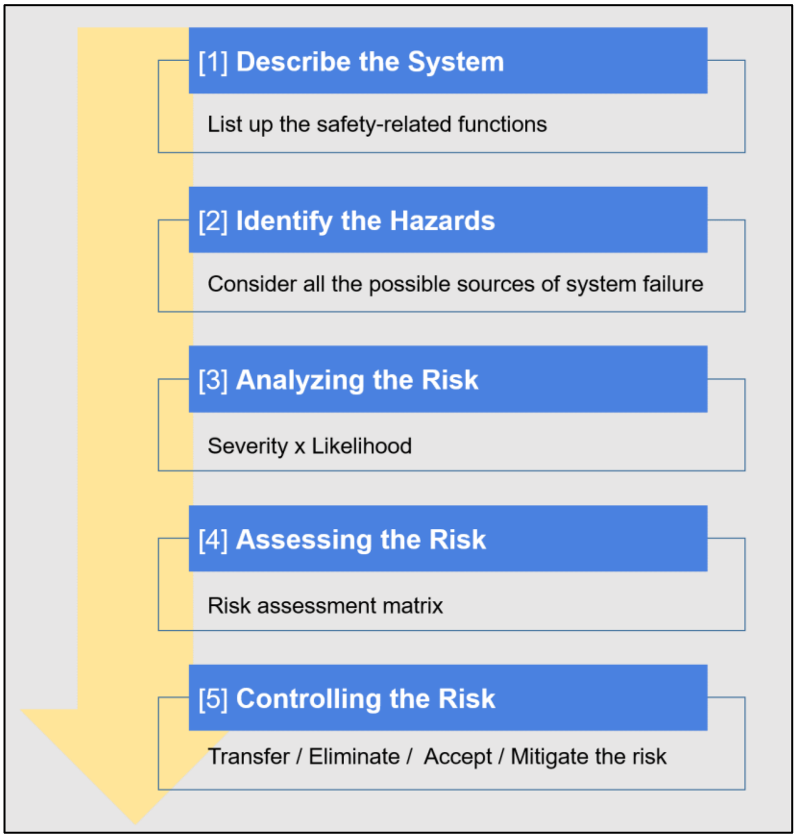
With each fiscal year airport plan or reevaluation of the airport budget, what could be improved? What are gaps or inefficiencies that have been found in practice? Analyze the given feedback and determine proper corrections. An example may be confusion due to inadequate training or a failure to uphold the system. Return to phase one and work through the process again - maybe no improvements are necessary, maybe something small needs to be addressed. Perhaps regulations have changed, or issues with funding need to be addressed. Take this phase to reevaluate the system and adjust accordingly.

Safety Risk Assessment

Safety, the state being free of unacceptable risk, is a fundamental value that airport operators pursue. The FAA requires all airports in the U.S to develop and implement a Safety Management System (SMS) as the means of detecting and correcting safety problems before realizing an accident or incident. As outlined in Advisory Circular 150/5200-37 of FAA, SMS is a formal, top-down, organizational wide approach to managing safety risk and assuring the effectiveness of safety risk controls. It consists of four main components; Safety policy, Safety Risk Management, Safety Assurance and Safety promotion. Safety Risk Management is the primary aspect of any SMS and can be divided into five phases as described in Figure 4.

Figure 4

Safety Risk Management Process (FAA AC 150/5200-37)



An airport's pavement management system should mitigate the likelihood of pavement failure that may result in damage or injury, as well as make cost-effective decisions by adhering to a given pavement management plan. When airport pavement is not monitored and maintained properly, hazards may occur. A hazard, as described by ICAO in Safety Management Manual "is a condition or an object with the potential to cause death, injuries to personnel, damage to equipment or structures, loss of material, or reduction of the ability to perform a prescribed function" (ICAO, 2018). Table 5 provides the hazards related to airport pavement deterioration have been derived using a Failure Mode and Effects Analysis (FMEA) framework.

Table 5

Failure Modes and Effects Analysis of Pavement Management Systems

Potential Failure Modes	Potential Effects of Failure	Severity (High 5, Low 1)	Potential Causes of Failure	Likelihood (High 5, Low 1)	Risk Priority Number (RPN)
A. Lapse/delay in pavement monitoring	Missed inspection	2	Tasks improperly allocated	2	4
	Pavement data not collected		Miscommunication		
	Premature pavement deterioration		Attention shifted elsewhere (emergencies, delays)		
B. Failure to properly evaluate collected pavement data	Maintenance not performed	2	Tasks improperly allocated	2	4
	Premature pavement deterioration		Attention shifted elsewhere (emergencies, delays)		
			Improper training		
C. Personnel incompetence or staff turnover	Lapse in communication	3	Improper training	3	9
	Unfinished work		Miscommunication		
	Incorrect data recorded		Rushed or incomplete work		
D. Lapse/delay in pavement maintenance	Defect allowed to worsen	4	Operations not prioritized	3	12
	Potential damage to aircraft/persons		Attention shifted elsewhere (emergencies, delays)		
	FOD creation from broken pavement		Lack of materials or equipment		
E. Improper maintenance performed	Defect not corrected, allowed to propagate	4	Improper training	2	8
	Defect made worse		Lack of materials or equipment		
	Potential damage to aircraft/persons		Rushed or incomplete work		

Table 6 lists these subsequent hazards that may occur as a result of a gap in pavement management. Safety Assessment Tables in FAA order 5200.11A Appendix C are used to determine the likelihood and severity of outcome of hazards. The outcome of these hazards, in the event of a failure to monitor or maintain airport pavement, can lead to a faulty decision on when or what to pave, resulting in surface cracking and the creation of loose fragments and chips. These risks may prove costly to the airport, and even result in death or injury to employees or passengers in extreme cases being overlooked and therefore not rehabilitated or repaired.

Table 6

Safety Risk Matrix (per FAA AC 150/5200-37)

High Risk		**Severity**				
Medium Risk **Low Risk**		**Minimal** **1**	**Minor** **2**	**Major** **3**	**Hazardous** **4**	**Catastrophic** **5**
Likelihood	**Frequent** **5**					
	Probable **4**					
	Remote **3**			**C**	**D**	
	Extremely Remote **2**		**A, B**		**E**	
	Extremely Improbable **1**					

The majority of hazards may be transferred and mitigated through a systematic design approach, the involvement of operation experts, and ongoing training. If pavement is not monitored and maintained to be in operable condition, the airport will suffer the costs. The cost of these hazards being realized will be further discussed in the cost-benefit analysis.

Projected Impact

This section will address the financial requirements and sustainability potential for implementing this design. This is done through a cost-benefit analysis and sustainability assessment. The sustainability assessment will focus on an Environmental, Operational, Natural Resource, and Social (EONS) model and United Nations Sustainable Development Goals (SDG).

1. Cost-Benefit Analysis

The viability of developing and maintaining an airport pavement plan is assessed using a cost-benefit analysis. Our strategy for supporting decision making is to be as conservative as possible. To provide a more tangible dollar value analyst, the team will use the assumption of an airport not yet implemented a PMP having a 5,000ft long and 150ft wide runway. Since our design aims for an airport to implement a cost-efficient procedure, the time scale of 10 years will be used to demonstrate how quickly an airport can receive return on investment.

1.1. Costs

The costs are divided into two stages: research and development (R&D), and implementation and operation. The R&D section includes the cost of initial development as well as expert review. As previously stated in the safety study, many risks associated with our system failure may be avoided by properly developing accounting for expert opinions. Table 7 provides the detailed cost of the R&D stage. The initial development period of 15 hours over 12 weeks is used because this is the time the group spent working on the ACRP design competition. Once the design is chosen for next step research, it is expected that graduate students will work full-time for at least four weeks to complete the final design that can be applied directly to airports. The team did not overlook the importance of holding regular workshops and meetings with airport experts and directors.

Since the FAA provides grants for preparation of PMP to an airport that does not have a custom PMP, the cost for the airport can be mitigated. Costs can be spread out over a number of airports if the design is widely adopted.

Table 7

Costs for Research and Development for a PMP

Stage	Item	Rate	Qty.	Total	Notes
R&D (Initial)	**Labor- University Design Competition to Develop Concept**				
	Graduate Student Research	$30/hr	720	$21,600	15 hours/week*4 students*12 weeks Purdue University student rate ($30)
	Faculty Advisor	$100/hr	60	$6,000	5 hours/week*1 advisor*12 weeks Purdue University advisor rate ($100)
	Subtotal			**$27,600**	
R&D (Review)	**Labor- Professional R&D to review the plan**				
	Graduate Student Assistance	$30/hr	320	$9,600	40 hours/week*2 students*4 weeks Purdue University Student rate ($30)
	Airport Personnel	$120/hr	120	$14,400	10 hours/week*3 experts*4 weeks
	Airport Director	$150/hr	4	$600	1 hour/week*1 expert*4 weeks
	Subtotal			**$24,600**	
Overhead Cost				**$5,220**	10% of project cost (travel, office supplies, tax, etc.)
Total				**$57,420**	**Note: one-time cost**

Note: Inspired by the ACRP Cost-Benefit Analysis Resource Video (Byers, 2016)

The design aims for providing a more systematic and data-based approach to airports for their pavement management. Costs related to the pavement such as inspection, maintenance are already in the airport's budget. Nevertheless, there might be a slight additional cost to maintain the plan and the team described it in Table 8 following the design phases. The cost of developing the training manual and teaching is also covered. The time required to educate them and train the employees is also considered. PAVEAIR does not charge a software fee.

Table 8

Airport Costs for Designing and Maintaining a PMP

Stage	Item	Rate	Qty.	Total	Notes
Phase 1	**Airport Pavement Project Definition**				
	Labor	$45/hr	10	$450	5 hours/week*2 employees*1 week (Compiling Standards, inventory)
	Subtotal			**$450**	
Phase 2	**Incorporate PMP in to Airport Plan and Budget**				
	Software	$0	1	$0	FAA's PAVEAIR is free
	Training Expenses	$45/hr	5	$225	5 hours/week*1 employee*1 week
	Labor	$45/hr	10	$450	5 hours/week*2 employees*1 week
	Materials/Equipment	$300	1	$300	Training materials including maintenance supplies
	Subtotal			**$975**	
Phase 3	**Incorporate PMP in to Airport Maintenance Plan**				
	Inspections	$45/hr	156	$7,020	1.5 hours/week*2 employees*52 weeks
	Pavement Repair	$2,411.04/mo.	12	$28,932	Based on estimated costs of runway maintenance, including materials and labor monthly average over a runway life cycle (EATSAP, 2011; Applied Research Associates, Inc., 2016)
	Subtotal			**$35,952**	
Phase 4	**Reevaluate and Improve the PMP**				
	Labor	$45/hr	10	$450	5 hours/week*2 employees*1 week
	Subtotal			**$450**	
Annual Subtotal				**$37,827**	
10-year total				**$378,270**	

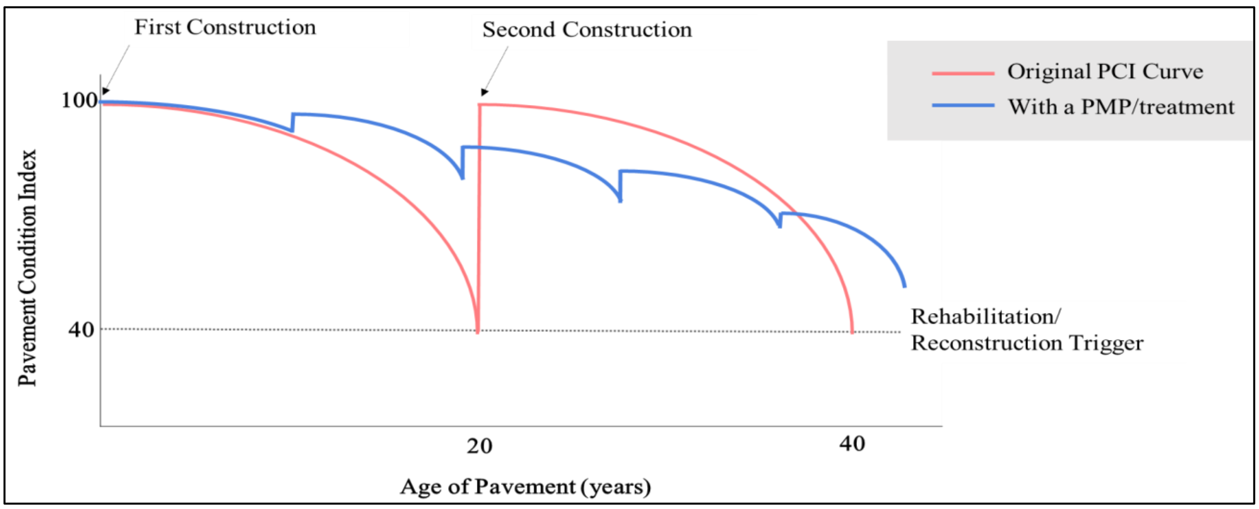
Note: The final total in Table 8 is a conservative estimate. An airport may not need to use every phase every year, or every cost in a given phase.

1.2. Benefits

PMP has a significant benefit in that it nearly doubles runway useful life while also increasing safety. PMP provides regular maintenance, extending the life of the pavement and drastically lowering the cost of reconstruction. This is a significant financial benefit in the long run. Figure 5 compares the life of a pavement without treatment to the life of a pavement with treatment. We can clearly see that with adequate treatment, the runway degrades at a low rate and life is nearly doubled. It saves time and money on reconstruction.

Figure 5

Pavement's life span comparison: Original Vs. Treatment applied



Note: Adapted from Figure 2 of Advisory Circular 150/5380-7B. Airport Pavement Management Program by FAA (2014). Retrieved from https://www.faa.gov/documentLibrary/media/Advisory_Circular/150-5380-7B.pdf

The second big monetary benefit is the avoidance of loss due to runway closure. It is calculated under the assumption that deploying PMP will prevent at least one day of runway closure due to FOD events or heavy construction work on runway. Table 9 summarizes the direct benefits of implementing a PMP for airports.

Table 9

Direct Benefits to Airport for Implementing a PMP

Item	Rate	Qty.	Total	Notes
Extend runway useful life cycle **by 100%**	$0.617/sq.yd.	83,333 sq.yd (1,500,000sq.ft)	$51,416	Cost avoidance of $0.617/sq.yd for 1 year compared to unmaintained runway (WHPacific, 2012)
Avoid one-day of downtime due to runway closure	$16,318/day	1 day	$16,318	Average revenue per day for non-hubs (Secretary of Transportation, 2020) In an airport with 10,000movements, Engine FOD event 3 times/year, Tire event 10 times/year, 1 fuselage damage
Annual subtotal			**$67,734**	
10-year total			**$677,340**	

Table 10 explains the benefit-cost ratio. The cost of R&D is a one-time investment, and the other cost and benefits are calculated over a ten-year period. The system has a benefit to cost ratio of at least 1.57 when deploying and maintaining it.

Table 10

Cost and Benefit of Airport operating with PMP 10 years

Cost	**Rate**	**Qty**	**Total**	**Remarks**
Research and Development cost	$52,200	1	$52,200	Table 7
Airport Costs for Designing and Maintaining a PMP	$37,827/year	10yrs	$378,270	Table 8
Subtotal Cost			$430,470	
Benefit	**Rate**	**Item**	**Total**	**Remarks**
Extend runway useful life cycle	$51,416/year	10yrs	$514,160	Table 9
Avoid downtime due to runway closure of 1 day/year	$16,318/year	10yrs	$163,180	Table 9
Subtotal Benefit			$677,340	
Benefit to Cost Ratio			**1.57**	**Benefit Outweighs cost**

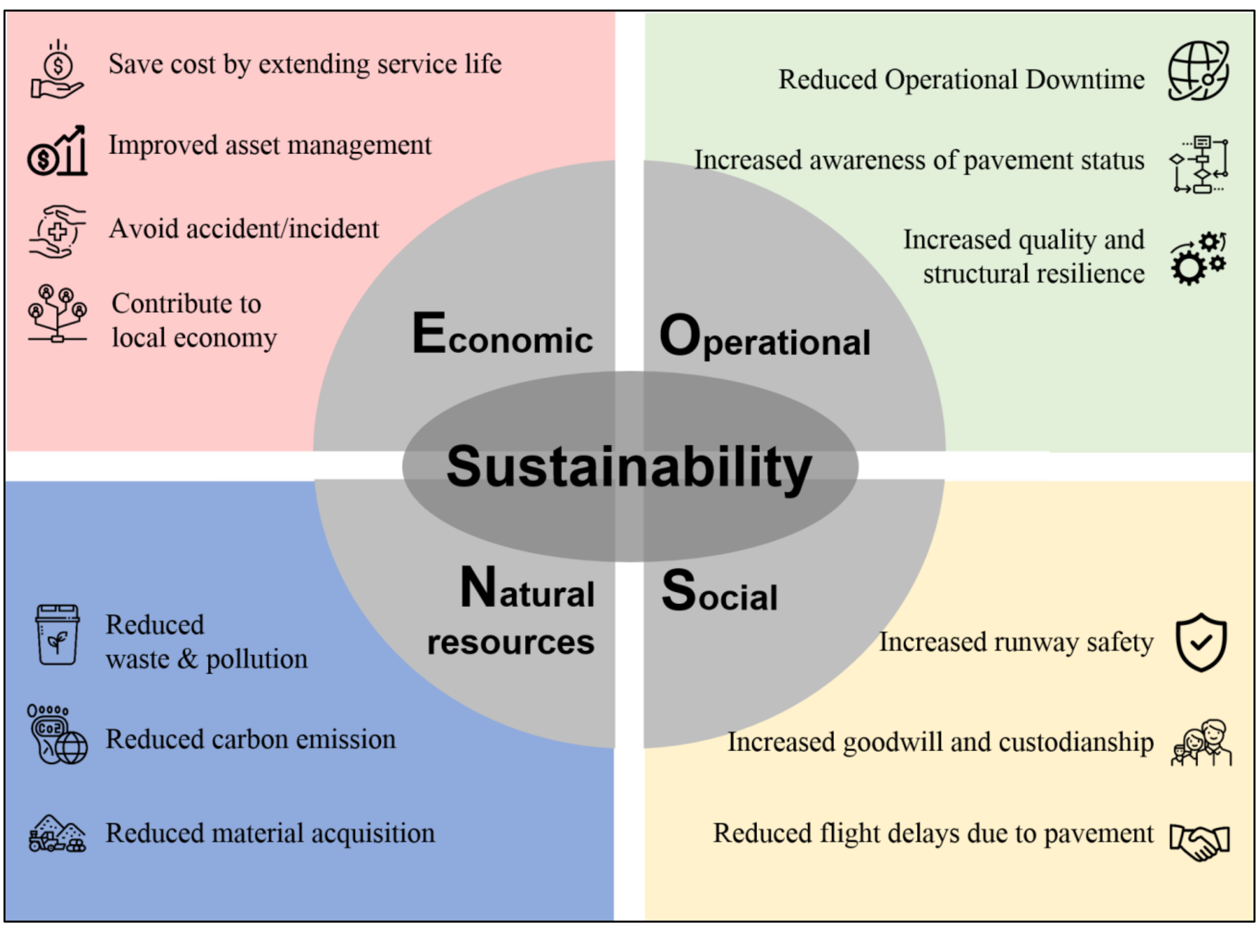
There are a variety of qualitative benefits that contribute to the airport's long-term sustainability. These advantages will be discussed in the following section.

2. Sustainability Assessment

One of the goals of the ACRP Competition is to raise awareness about the importance of airport sustainability by addressing modern issues and proposing creative solutions. In the aviation industry, sustainability is defined by the Airports Council International (ACI) as “the balance between environmental, social, and economic factors to ensure lasting prosperity” (ACI, 2021a). The group used the EONS (Economic, Operational, Natural Resources, and Social) framework to examine the sustainability of the design corresponding to the definition. Figure 6 describes how this design can aid airport sustainability per the EONS model.

Figure 6

Sustainability impacts from the design



2.1. Economic Impact

Economic impact involves not just an organization's financial benefit but also can increase interest for stakeholders, according to John Elkington, who coined the term "Triple Bottom Line." (Elkington, 2018). In light of this interpretation, operating a safe and seamless airport contributes to local economies by providing jobs and connecting cities.

A PMP has direct and indirect potential for financial impacts. As discussed in FAA *AC 150/5380-7B*, Airport PMPs can support cost-effective decision making about maintenance and rehabilitation, enabling airports to save costs by extending service life of pavement. Because the movement area is one airport area that requires a significant amount of acquisition and maintenance, PMP can be considered an asset management tool.

Suggested by the *Pavement Maintenance Program Ten-Year Performance Review* (WHPacific, 2012) study, airfield pavement service life can be extended by 104.4% compared to unmaintained pavement. Also, optimum decisions of rehabilitation save a significant amount of overlap investment, resulting in cost savings of 23.8% (WHPacific, 2012).

Another advantage of a PMP is that it serves to promote more accurate and safe surface pavement management. Failing to maintain a proper state of the movement area surface might result in Foreign Object Debris (FOD), which is a hazard of an aircraft operating on the movement area. If any accident or incident occurs, the runway should be closed for handling and investigating. As previously mentioned in the cost-benefit section, the economic value of a runway for one-day can be as large as $16,318 at non-hub airports.

2.2. Operational Impact

As described in FAA *AC 150/5380-7B*, PMP facilitates a consistent and methodical approach to pavement management. This includes monitoring, treatment application decision-making, and budgeting. There are criteria and guidelines prepared in an airport's PMP and future requirements can be determined by previous pavement work. The frequency of heavy work can be decreased and predicted and reduced with smaller maintenance projects. A methodical approach to pavement maintenance and reliable data records also aids the airport and FAA in determining long-term funding and encouraging participation.

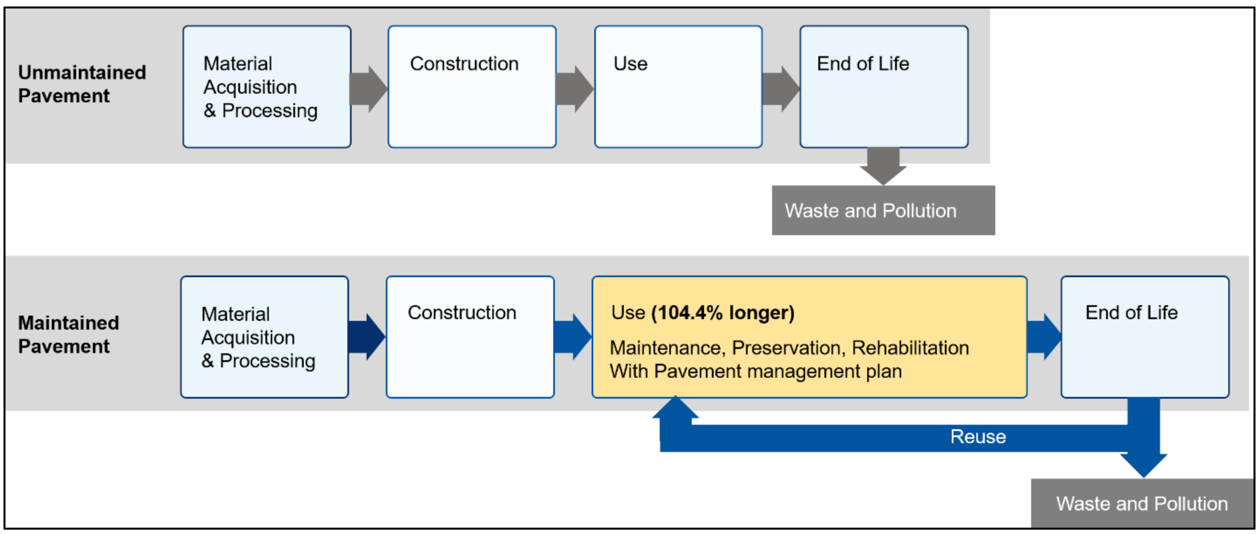
Global aviation safety related bodies such as the FAA, ICAO, and ACI have established standard protocols for pavement inspection. Inspections rely heavily on visual procedures, which vary based on one's subjective experience and knowledge. Some airports use core sampling which is costly and may affect pavement deterioration. Due to limited funding and awareness, small airports may not be able to afford regular inspections and maintenance. Using a PMP helps to ensure that the pavement quality remains constant.

2.3. Environmental Impact

ICAO's *Resolution A40-18* stresses the need for environmentally conscious practices in response to potential climate change effects (ICAO, 2019). Our design can be regarded as a greener solution. Movement area comprises a large portion of airport paved surfaces (e.g. concrete or asphalt). Even before the construction material is used, CO_2 is produced due to emissions coming from high-heat manufacturing processes and off-road construction equipment, and the indirect emission such as energy used to procure and transport materials. Because of its size, airports are frequently pointed out as being environmentally unfriendly not only for aircraft direct emission but also the land take and related CO_2 generated. The longer usage of pavement can prevent negative impacts on the environment. As depicted in Figure 7, material acquisition can be reduced, the carbon footprint created during the processing of materials and construction can be lowered, and the waste and its pollution can be decreased with decreased frequency of rehabilitation and repavement in the long run.

Figure 7

Pavement Life Cycle Comparison



2.4. Social Impact

Social value refers to the wellbeing of customers (passengers and visitors of a given airport), staff, business partners (often airlines), government and local communities. Airlines might be the most affected party by the condition of pavement. If FOD occurs on an operating runway, it can directly cause accidents and incidents that cost airlines from hundreds to millions of dollars. Table 11 lists the average cost for aircraft damage. These incidents and accidents will lead to a delay of flights which consequently generate passenger inconvenience.

Table 11

Direct cost to airlines caused by Foreign Object Damage (McCreary, 2008)

Category	**Rate**	**Cost per 10k movements**
Engine Maintenance	1 event per 3,200 aircraft movements	$205,000
Tire Replacements	1 blade pair replaced per 5,900 movements	$57,000
Aircraft fuselage damage	1 tire FOD event per 1,030 movements	$926
Total Direct Cost of FOD		$263,000

Note: the costs listed in Table 11 are not included in the cost benefit analysis; however, preventing one of these incidents is beneficial to airlines and airports

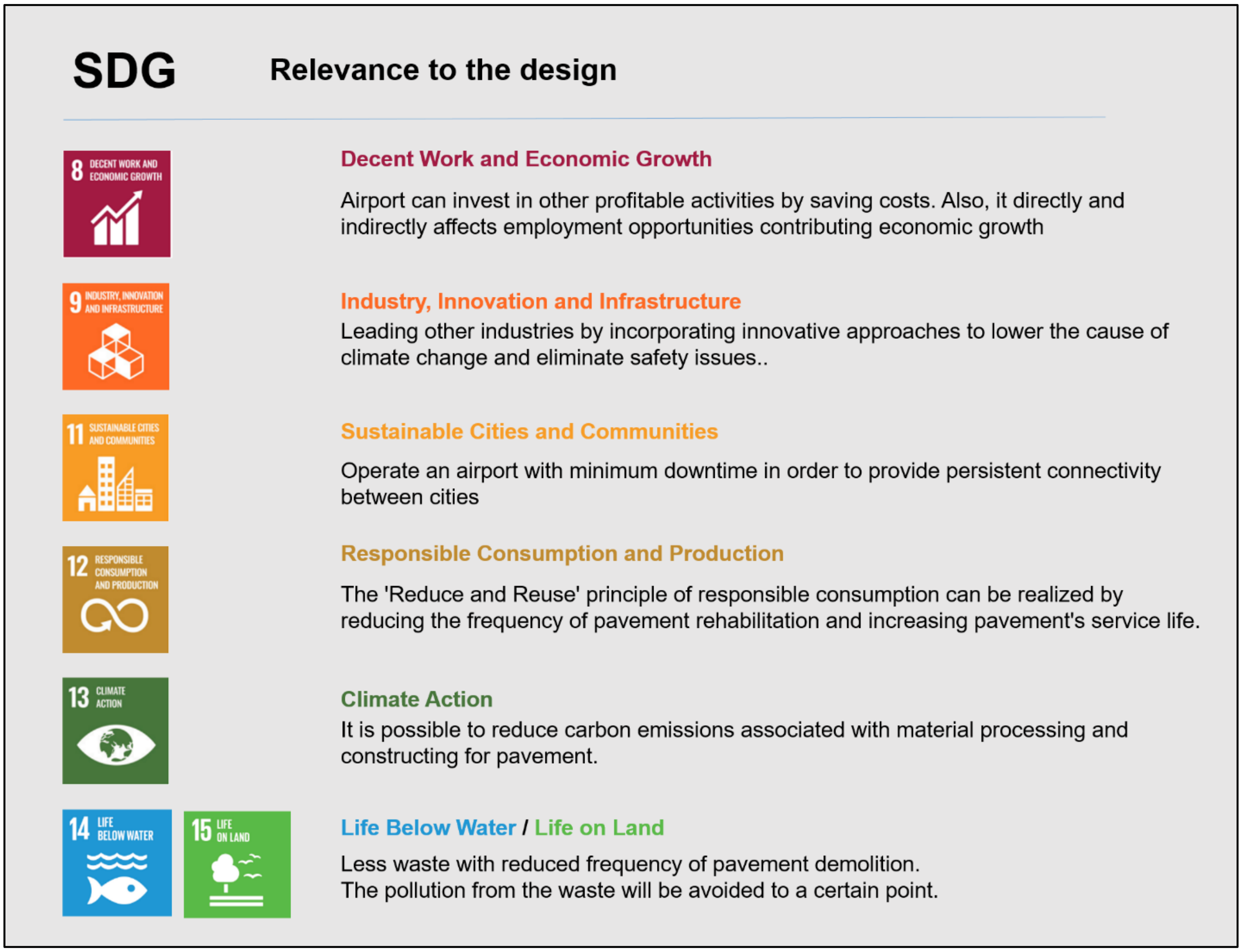
Another significant advantage is the goodwill and trust of the general public and the board of directors/shareholders. This would aid in the establishment of a positive reputation and the attraction of additional investment from investors.

Employees are also benefited with implementing a PMP. An unbiased decision-making process and systemic foresight in pavement management contribute to a more decent workplace. In this regard, using a PMP contributes to employee morale and productivity as the plan contains accumulated documentation with predetermined procedures.

Minimizing downtime benefits not only the airport but also its associated stakeholders. Passengers and cargo are transferred when an airport is operational, making the catchment region active. Once the impact of a Plan for Airport Pavement Management and Maintenance is established, it may be expanded to other industries that are leading the way in terms of safety innovation. Figure 8 describes how this design can aid airports in achieving United Nations Sustainable Development Goals (SDSs).

Figure 8

Relevance to Sustainable Development Goals



Conclusion

Airport movement areas are covered with paved surfaces and are directly linked with the safe operation of aircraft. Safety is the first priority that the aviation industry pursues, while risks should be treated at the lowest practical level as defined by the FAA (Timmons, 2016). Given that the majority of investment is required for pavement construction and rehabilitation, extending pavement lifespan in a cost-effective way is significant. Our systematic decision-making process for establishing a PMP can assist airport development in a timely and cost-effective manner.

Our design can contribute to promoting the airport's sustainability by taking into consideration the ESG (Environment, Social, and Governance) perspectives, which align with the collective goal of international aviation. The effective and customized pavement plan for individual airports not only supports saving the cost for constructing and maintaining pavement throughout its life cycle, but also reduces the negative impacts such as carbon emission and pollution from its material acquisition and waste of removing the old pavement. Related stakeholders such as the local community, employees, and airlines will benefit from this pavement plan.

Lastly, while preparing for this competition, we have learned a lot about the important role of airports as well as the efforts of the aviation sector including FAA, ACRP, airports, researchers, and engineers to boost aviation sustainability. It was a wonderful opportunity for us to dig deeper into the challenges that airports face by engaging with real-world professionals, generating ideas, and refining them from a range of viewpoints. Our team members come from a variety of cultural and academic backgrounds. We hope to see the application of our PMP in industry practices as an effort to increase the sustainability of airports.

Appendix A: Contact Information

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Appendix B: Description of University

Purdue University

"PERSISTENT INNOVATION. TOGETHER."

Purdue University, the land, sea grant University in Indiana, is a vast laboratory for discovery. Purdue is a public university known not only for science, technology, engineering, and math programs, but also for our imagination, ingenuity, and innovation. It's a place where those who seek an education come to make their ideas real – especially when those transformative discoveries lead to scientific, technological, social, or humanitarian impact.

Founded in 1869 in West Lafayette, Indiana, the university proudly serves its state as well as the nation and the world. Academically, Purdue's role as a major research institution is supported by top-ranking disciplines in pharmacy, business, engineering, and agriculture. More than 39,000 students are enrolled here. All 50 states and 130 countries are represented. Add about 950 student organizations and Big Ten Boilermaker athletics, and you get a college atmosphere that's without rival.

School of Aviation and Transportation Technology

Purdue University's School of Aviation and Transportation Technology, one of six departments and schools in the Purdue Polytechnic Institute, is recognized worldwide as a leader in aviation education. All seven of Purdue's Aviation and Transportation Technology majors are world-class educational programs. The mission of the School of Aviation and Transportation Technology is to prepare the next generation of leaders and change agents for the transportation sector. The School will be the recognized global leader in aviation technology education through excellence in faculty, students, curricula, laboratories, and mutually beneficial partnerships (Purdue, n.d) .

Appendix C: Description of interaction with industry contacts and airport operators

Industry interaction contacts

Affiliation	Title	Name
Academia		
Purdue University School of Aviation and Transportation Technology	Professor	Dr. Stewart Schreckengast
	Professor	Dr. Damon Lercel
	Professor	Dr. Joseph Hupy
Airports		
Corpus Christi International Airport	Deputy Aviation Director	Tyler Miller
	Airport Development & Construction Manager	Victor Gonzalez
West Virginia International Yeager Airport	Airport Director & CEO	Nick Keller
Civil Engineering Organizations		
WSP	Vice President and National Aviation Planning Manager	John van Woensel
Garver	Aviation Project Manager	Derek Mayo
	Maintenance Program Leader	Aaron Smith
Airport Design Consultants, INC.	Practice Manager	Alan Peljovich
FAA		
FAA Technical Center	Researcher	Dr. Navneet Garg

Purdue University School of Aviation and Transportation Technology

Dr. Stewart Schreckengast of the Purdue University School of Aviation and Transportation Technology has many years of hands-on experience in airport safety. Schreckengast has held positions as a Naval Aviator, Consultant with MITRE, Senior Aviation and System Safety Analyst for FAA, Technical Consultant with ICAO, Certified Member of American Association of Airport Executives, and a Researcher and Educator at Purdue University. The team learned from Dr. Schreckengast about the importance of maintaining pavement, particularly in environments with a changing or extreme climate. We also learned that cost effectiveness is as important as safety, and that it is crucial to determine a method that saves money on labor and supplies while simultaneously reducing runway downtime.

Dr. Damon Lercel, has over 30 years of aviation experience and is currently researching topics related to Unmanned Aircraft Systems and Advanced Air Mobility. From discussing with Dr. Lercel, the group learned about surface detection technology such as LIDAR and projects that utilize drones for runway inspections. From this discussion, the group decided that the use of LIDAR or drones would not be the most optimal tool for crack detection given the current technology, costs, and disruptions to airport operations.

Dr. Joseph Hupy has more than 20 years of experience researching the integration of geospatial data into Geographic Information Systems (GIS) software. During this meeting, the group learned that photographic imaging could augment visual inspections of paved surfaces, and discovered research projects where Red-Green-Blue (RGB) photo imaging had been utilized for this purpose. The group learned about the ability of sensing equipment to detect micro-cracks, produce thermal images, and determine surface depth. However, the use of this equipment requires adequate training and education in terms of handling and interpretation.

Corpus Christi International Airport (CRP)

Tyler Miller, the deputy aviation director of Corpus Christi International Airport, and his team consisting of Victor Gonzalez (Airport Development & Construction Manager) met with the group. In this meeting, the group learned valuable information about the real-world practicality of pavement management as well as the limitations that may restrict an airport from implementing a PMP. The group learned about the PMP currently being used at Corpus Christi International Airport. This meeting was joined by representatives from Garver whose contributions will be addressed below. From this meeting, the group learned about the need for crack detection in order to combat deterioration caused by aircraft loads and climate, as well as provided insight into how many airports have yet to establish their own pavement management plans despite FAA and state DOT recommendations. This meeting caused the group to redirect this proposal from sensing technology to a procedural method for establishing and maintaining PMPs.

West Virginia International Yeager Airport (CRW)

Nick Keller, Airport Director & CEO of Yeager Airport & **Aaron Peljovich**, Practice Manager at Airport Design Consultants, met with the group. The group learned about pavement management projects at Yeager Airport. From this meeting, the group was able to realize the realistic limitations airports face when constructing a PMP, such as available technologies, costs, and organization.

WSP

From a meeting with **John van Woensel**, Vice President and National Aviation Planning Manager at WSP, the group learned about the two most common techniques for pavement inspection, eye examination and core sampling, and how different findings can be reached using differing techniques on the same pavement. This makes determining when and what is required for pavement maintenance challenging, and also strongly relies on the opinion of an expert. The group also discovered that small airports can lack specialized personnel and funding.

Garver

Derek Mayo (Aviation Project Manager) joined by **Aaron Smith** (Maintenance Program Leader) from Garver were in attendance during the meeting with Tyler Miller of Corpus Christi. The group learned from these Garver representatives about a 10 year study spanning across Oregon airports that suggested the implementation of PCI and PMP can increase airport pavement life by 10%. The group also gathered that there is a need for further study of state DOTs assistance in regular inspections, friction measurements, and PCI inspections.

FAA Personnel

Dr. Navneet Garg, a researcher at the FAA William J. Hughes Technical Center, met with the group to further discuss the current and future states of airport pavement, as well as the pavement management softwares the FAA provides free of charge for airport use. The group learned from Dr. Garg about properties and failure modes of concrete and asphalt, as well as the current state of recycled material in pavement, such as how currently recycled material is not permitted for use in runways. The group also learned about how pavements need to be specifically designed in accordance with local environmental and traffic conditions, and the need for greener technologies in order to enforce airport sustainability.

Appendix E: Evaluation of Educational Experience Provided by the Project

Students

1. Did the Airport Cooperative Research Program (ACRP) University Design Competition for Addressing Airports Needs provide a meaningful learning experience for you? Why or why not?

This design competition was a very meaningful educational experience for this group. All members pushed out of their comfort zones when researching for this project, whether that entailed speaking with industry experts or compiling information for the literature review. Everyone in the group got the opportunity to work on a diverse team, coordinating tasks and meetings. This project required extensive research, paper and interview based. The group had to educate themselves on a portion of airport operations and maintenance that they may not have been very familiar with prior, and the information that was discovered and compiled was incredibly valuable. All group members had valuable experiences in the process of developing this proposal, and look forward to taking what we learned and applying it in future tasks.

2. What challenges did you and/or your team encounter in undertaking the competition? How did you overcome them?

This group encountered several challenges during the development of this design proposal. One of those challenges involved a constant shift in the project goal as the group adapted in response to discussions with industry experts. This design had an original intention of researching sensors for surface and subsurface crack detection in airport movement areas, which shifted to a standardized pavement management plan, and finalized with a focus on decision-making guidance for establishing a customized pavement management system.

Another challenge involved time management and adhering to self-imposed deadlines. All graduate members are involved with work or families, so each individual had to work around their own schedules or the group had to come together as a team to problem solve.

In addition, the group struggled extensively with achieving a desired quality of the proposal. Several revisions to this proposal took place over the span of the project, all with the goal of submitting a document that goes above the standard guidelines and is a worthy submission to the ACRP design competition.

3. Describe the process you or your team used for developing your hypothesis.

The team began with an idea to research different surface and subsurface sensor technologies, compare them, and determine which may be the most appropriate to aid in airport movement area pavement inspection. After several project goal redirections, the group decided to focus on a decision-making process to aid airports in the development or sustainability of a given pavement management system. In order to propose an effective hypothesis, the group had to compile pertinent regulations and standards per the literature review. Also, in the literature review, the group gathered current state practices of maintenance and monitoring. Once information had been gathered through research and discussion with industry experts, a decision-making approach was able to be formulated to the development of an airport PMP.

4. Was participation by industry in the project appropriate, meaningful and useful? Why or why not?

Participation by industry was absolutely crucial to this project design. Without industry interaction, it would be incredibly difficult to truly understand the scope of what airports are doing for pavement management. If the group had stuck to paper-based research, a deeper understanding of the practicality and feasibility of the proposed design's solution may be in question. By discussing this project with airport directors, construction consultants, maintenance personnel, and other industry experts, the group was able to adapt and shift the project's focus into something that was perceived as more helpful to airports overall. In addition, the group was able to identify gaps or issues in current state processes that could be addressed through this proposed design. The team is truly thankful for the chance to discuss pavement and pavement management with all industry contacts involved.

5. What did you learn? Did this project help you with skills and knowledge you need to be successful for entry in the workforce or to pursue further study? Why or why not?

The group learned a great deal during the development of this project. One of the greatest skills developed involved working in a diverse team, not just ethnically, but also with respect to academic backgrounds and personalities. This group consisted of students with educational backgrounds in aerospace engineering, aviation engineering and technology, aviation management, and professional flight. While these differences in backgrounds proved primarily helpful with providing differences in perspectives, those same perspectives could bring bias. However, the group all learned to work together and communicate ideas effectively.

In addition, the group became more accustomed to reaching out to industry professionals for help or advice regarding this project. This task was incredibly anxiety inducing at first, but as more professionals were contacted and more meetings were held, the group started to become comfortable with interacting with those who may be future peers in aviation. Overall, the team firmly believes that the skills and knowledge developed during this project have been incredibly beneficial to learn and all members believe that those same skills will benefit each other in a career or further study.

Faculty

1. Describe the value of the educational experience for your student(s) participating in this competition submission.

For this team, the experience was amazing. As an instructor, I am especially proud of the way this team seized the opportunity. For this class, the educational experience provided by this competition is an opportunity for student teams to respond to a Request for Proposals (RFP) with a proposal to design a specific airport improvement that will respond to one of the challenge areas and increase sustainability in four dimensions: economic, operational, environmental, and social, and to connect their design proposal to one or more UN Sustainable Development Goals. One thing that I encourage is to have small (3-4 students) teams made up of a diverse mix of cultural, social, and/or disciplines. In this way, the teams are practicing skills that are used in industry (proposing ideas for improvement on paper and in presentations, developing justifications to move the idea forward, collecting ideas and deciding on implementation, and working in teams made up of a varied group of people). One of the unique values of this experience is for the team members to interact with experts. This team excelled at it – not only the experts on this list but others as well. It is valuable because the airport operators and industry experts volunteer their time and share their experiences with these students. Due to this sharing, the teams make changes to the design or implementation, and gain experience is obtaining and listening to feedback.

2. Was the learning experience appropriate to the course level or context in which the competition was undertaken?

Yes. This competition is one option in a one-semester graduate level course in sustainability. The other option is to prepare a manuscript for publication in an academic journal.

Thankfully, this team chose the competition as it helped the team struggle in the beginning and come together in the end.

3. What challenges did the students face and overcome?

The team started with pavement issues at airports. Enamored with high-tech equipment and having little to no formal education on pavements, the first challenge was to quickly gain knowledge on airport surfaces and the repair technologies that are used or are under development. After talking with airport managers at two airports, and to other experts across the country, the team shifted focus from pavement repair technologies to developing a Pavement Management Plan (PMP). The team was reading voraciously, and was searching for information when they found a study showing that a PMP can be used to help an airport extend the life of airport surfaces. Speaking with other experts helped them understand that a PMP is a good first step to prioritizing projects, obtaining budgets, and implementing timely repairs. This helped focus the team to find a design improvement that helps airports of any size, and especially those airports that cannot afford expensive repaving, consultants, or runway closures.

4. Would you use this competition as an educational vehicle in the future? Why or why not?

Definitely, yes! These four students come from four different education backgrounds and three different countries. We do this project within one semester, that is effectively 8-weeks after subtracting other class assignments, tests, and spring break. It is a challenge for the teams to develop as a team and become productive in that short 8-week time span between project teaming and project delivery. In my opinion, this is the type of project that forms both the competence and confidence that they can hit the ground running in their first 90 days on the job.

5. Are there changes to the competition that you would suggest for future years?

As always, keep updating the challenge areas to include existing project ideas and newer technologies.

Appendix F: References

Aeronautics and Space, 14 C.F.R. § 139 (2004). *Certification of Airports. 1 Applicability* https://www.ecfr.gov/current/title-14/chapter-I/subchapter-G/part-139

Air Transport Action Group. (2021). *Waypoint 2050*. Retrieved on March 02, 2022, from https://aviationbenefits.org/environmental-efficiency/climate-action/waypoint-2050/

Airports Council International [ACI]. (2021). *Sustainability strategy for airports worldwide 2021*. Retrieved from https://aci.aero/2021/11/16/aci-world-launches-inaugural-sustainability-strategy-report-for-airports-worldwide/

Applied Research Associates (2016, January). *Pavement Condition Report*. Retrieved on April 22, 2022, from https://www.in.gov/indot/files/Peru_2015.pdf

American Society for Testing and Materials [ASTM]. (2019). *Standard guide for pavement management implementation*. American Society for Testing Materials [ASTM]. Retrieved from https://compass.astm.org/document/?contentCode=ASTM%5C%7CE1889-97R19%5C%7Cen-US

American Society for Testing and Materials [ASTM]. (2020). *Standard test method for airport pavement condition index surveys*. American Society for Testing Materials [ASTM]. Retrieved from https://compass.astm.org/document/?contentCode=ASTM%7CD5340-20%7Cen-US

American Society for Testing and Materials [ASTM]. (2021a). *Standard Test Method for Nonrepetitive Static Plate Tests of Soils and Flexible Pavement Components for Use in Evaluation and Design of Airport and Highway Pavements*. American Society for Testing

Materials [ASTM]. Retrieved from https://compass.astm.org/document/?contentCode=ASTM%7CD5340-20%7Cen-US

American Society for Testing and Materials [ASTM]. (2021b). *Standard Test Method for Repetitive Static Plate Tests of Soils and Flexible Pavement Components for Use in Evaluation and Design of Airport and Highway Pavements*. American Society for Testing Materials [ASTM]. Retrieved from https://compass.astm.org/document/?contentCode=ASTM%7CD5340-20%7Cen-US

Blocher, E., Juras, P., & Smith, S. (2021). Cost management: A strategic emphasis. McGraw Hill LLC. Retrieved from https://books.google.com/books?id=dp%5C_YzQEACAAJ

Byers, D. (2016). ACRP Design Competition - Dave Byers - Guidance for Preparing Benefit/Cost Analyses [Video]. Virginia Space Grant Consortium. Retrieved on March 13, 2022, from https://www.youtube.com/watch?v=J1yRM1uPpcc&feature=youtu.be

Daniel, J. S., Mallick, R. B., Douglas, E., Jacobs, J. M., & Hayhoe, K. (2014). Impact of climate change on pavement performance: Preliminary lessons learned through the infrastructure and climate network (ICNet). *Climate Effects on Pavement and Geotechnical Infrastructure*, 1–9. Retrieved from https://ascelibrary.org/doi/10.1061/9780784413326.001

Eckrose, R. A., & Reynolds, W. G. (1991, January). Implementation of a Pavement Management System for Indiana Airports — A Case History. *Pavement Management Implementation*, 228–239. https://doi.org/10.1520/stp17805s

Elkington, J. (2018). 25 Years Ago I Coined the Phrase “Triple Bottom Line.” Here’s Why It’s Time to Rethink It. *Harvard Business Review*, 25, 2–5. Retrieved on March 03, 2022, from https://hbr.org/2018/06/25-years-ago-i-coined-the-phrase-triple-bottom-line-heres-why-im-giving-up-on-it

Energy Technology Systems Analysis Programme [ETSAP] (2011, August). Aviation Infrastructure. Retrieved on April 20, 2022, from https://iea-etsap.org/E-TechDS/PDF/T16_Aviation_Infrastructure_v4%20Final.pdf

Federal Aviation Administration [FAA]. (1997). *AC 150/5320-12C*. Measurement, Construction, and Maintenance of Skid-Resistant Airport Pavement Surfaces. Retrieved from https://www.faa.gov/documentLibrary/media/advisory_circular/150-5320-12C/150_5320_12c.PDF

Federal Aviation Administration [FAA]. (2009). *AC 150/5380-9*. Guidelines and Procedures for Measuring Airfield Pavement Roughness. Retrieved from https://www.faa.gov/documentLibrary/media/Advisory_Circular/150_5380_9.pdf

Federal Aviation Administration [FAA]. (2011). *AC 150/5370-11B*. Use of Nondestructive Testing in the Evaluation of Airport Pavements. Retrieved from https://www.faa.gov/documentLibrary/media/Advisory_Circular/150_5370_11b.pdf

Federal Aviation Administration [FAA]. (2014a). *AC 150/5320-17A*. Airfield Pavement Surface Evaluation and Rating Manuals. Retrieved from https://www.faa.gov/documentLibrary/media/Advisory_Circular/150-5320-17a.pdf

Federal Aviation Administration [FAA]. (2014b). *AC 150/5335-5C*. Standardized Method of Reporting Pavement Strength – PCN. Retrieved from https://www.faa.gov/documentLibrary/media/Advisory_Circular/150-5335-5c.pdf

Federal Aviation Administration [FAA]. (2014c). *AC 150/5380-6C*. Guidelines and Procedures for Maintenance of Airport Pavements. Retrieved from https://www.faa.gov/documentLibrary/media/Advisory_Circular/150-5380-6C.pdf

Federal Aviation Administration [FAA]. (2014d). *AC 150/5380-7B*. Airport Pavement Management Program (PMP). Retrieved from https://www.faa.gov/documentLibrary/media/Advisory_Circular/150-5380-7B.pdf

Federal Aviation Administration [FAA]. (2018). *AC 150/5370-10H*. Standard Specifications for Construction of Airports. Retrieved from https://www.faa.gov/documentLibrary/media/Advisory_Circular/150-5370-10H.pdf

Federal Aviation Administration [FAA]. (2019). *Order 5100.38D*. Airport Improvement Program Handbook. Retrieved from https://www.faa.gov/airports/aip/aip_handbook/media/AIP Handbook-Order-5100-38D-Chg1.pdf

Federal Aviation Administration [FAA]. (2020, September 30). *National Plan of Integrated Airport Systems (NPIAS) 2021–2025*. United States Department of Transportation. Retrieved on March 01, 2022, from https://www.faa.gov/airports/planning_capacity/npias/current/media/NPIAS-2021-2025-Narrative.pdf

Federal Aviation Administration [FAA]. (2021a). *AC 150/5320-6G*. Airport Pavement Design and Evaluation. Retrieved from https://www.faa.gov/documentLibrary/media/Advisory_Circular/150-5320-6G-Pavement-Design.pdf

Federal Aviation Administration [FAA]. (2021b). *Total AIP Grant Funds Awarded by Development and Funding Type*. Retrieved from https://www.faa.gov/airports/aip/grant_histories/annual_reports/media/Total-AIP-grant-funds-awarded-fy1982-2018.pdf

Federal Aviation Administration [FAA]. (2022). *FAA PAVEAIR*. Retrieved April 29, 2022, from https://faapaveair.faa.gov/

Gudipudi, P. P., Underwood, B. S., & Zalghout, A. (2017). Impact of climate change on pavement structural performance in the United States. *Transportation Research Part D: Transport and Environment*, 57, 172-184. https://doi.org/10.1016/j.trd.2017.09.022

International Civil Aviation Organization [ICAO]. (1990). *Standards and recommended practices for aerodromes: Annex 14 to the Convention on International Civil Aviation*. Retrieved from https://www.icao.int/APAC/Meetings/2015%20WAWG1/an14_1ed_1951.pdf

International Civil Aviation Organization [ICAO]. (2018). Safety Management Manual. Doc 9859 AN/474. Retrieved from https://skybrary.aero/sites/default/files/bookshelf/5863.pdf

International Civil Aviation Organization [ICAO]. (2019). *Resolution A40-18*. Retrieved from https://www.icao.int/environmental-protection/Documents/Assembly/Resolution_A40-18_Climate_Change.pdf

International Civil Aviation Organization [ICAO]. (n.d.). *Future of Aviation*. Retrieved from https://www.icao.int/Meetings/FutureOfAviation/Pages/default.aspx

McCreary, I. (2008) *The Economic Cost of FOD to Airlines*. Retrieved from http://fod-detection.com/wp-content/uploads/2009/12/the-economic-cost-of-fod.PDF

Mills, B. N., Tighe, S. L., Andrey, J., Smith, J. T., & Huen, K. (2009). Climate Change Implications for Flexible Pavement Design and Performance in Southern Canada. *Journal of Transportation Engineering*, 135(10), 773-782. Retrieved from https://ascelibrary.org/doi/10.1061/%28ASCE%290733-947X%282009%29135%3A10%28773%29

Mndawe, M. B., Ndambuki, J., & Kupolati, W. K. (2013). Revision of the Macro Climatic Regions of Southern Africa. *OIDA International Journal of Sustainable Development*, 6(1), 37-44. Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2343006

Murrell, S. D., Rada, G. R., & Schwartz, C. W. (1991, January). Airport Pavement Management: The Port of New York and New Jersey Experience. *Pavement Management Implementation*, ASTM International. 240–255. https://doi.org/10.1520/stp17806s

National Academies of Sciences, Engineering, and Medicine. (2010). *Recommended Guidelines for the Collection and Use of Geospatially Referenced Data for Airfield Pavement Management*. Washington, D.C.: The National Academies Press. https://doi.org/10.17226/22913

National Academies of Sciences, Engineering, and Medicine. (2011). *Common Airport Pavement Maintenance Practices*. Washington, D.C.: The National Academies Press. https://doi.org/10.17226/14500

National Academies of Sciences, Engineering, and Medicine. (2017). *Guidance for Usage of Permeable Pavement at Airports*. Washington, D.C.: The National Academies Press. https://doi.org/10.17226/24852.

National Academies of Sciences, Engineering, and Medicine. (2019a). *Guidelines for Collecting, Applying, and Maintaining Pavement Condition Data at Airports*. Washington, D.C.: The National Academies Press. https://doi.org/10.17226/25566.

National Academies of Sciences, Engineering, and Medicine. (2019b). *Climate Resilience and Benefit Cost Analysis: A handbook for Airports*. Washington, D.C.: The National Academies Press. https://doi.org/10.17226/25497.

National Academies of Sciences, Engineering, and Medicine. (2021). *Rapid Slab Repair and Replacement of Airfield Concrete Pavemen*t. Washington, D.C.: The National Academies Press. https://doi.org/10.17226/26322.

Purdue University. (n.d). *About the School of Aviation and Transportation Technology.* Retrieved on April 22, 2022, from https://polytechnic.purdue.edu/schools/aviation-and-transportation-technology/about

Timmons, W. (2016, September 29). ACRP Design Competition - Wes Timmons - Completing a Safety Risk Assessment [Video]. Virginia Space Grant Consortium. Retrieved on March 13, 2022, from https://www.youtube.com/watch?v=PX5GFC_RNYo

WHPacific. (2012). *Pavement Maintenance Program Ten-Year Performance Review: Oregon Department of Aviation*. Retrieved from https://www.oregon.gov/aviation/plans-and-programs/Documents/PMP/PMP%20Ten%20Year%20Performance%20Review.pdf