Investigating the Role of Climate on Airfield Pavement Deterioration and Distress Occurrence Using Data from PAVEAIR Online Database

by

Ebenezer Duah

A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science

Approved November 2021 by the
Graduate Supervisory Committee:

Hasan Ozer, Chair
Kamil E. Kaloush
Michael S. Mamlouk

ARIZONA STATE UNIVERSITY

December 2021

ABSTRACT

Differences in climatic conditions, aircraft traffic, and maintenance practices drive airfield pavements to perform differently. Through the Federal Aviation Administration's (FAA's) PAVEAIR online database and the National Oceanic and Atmospheric Administration's (NOAA's) online public platform, historical pavement condition and climate data from nearly 200 airfields in the dry freeze (DF), dry no-freeze (DNF), wet freeze (WF), and wet no-freeze (WNF) climatic regions were collected to evaluate pavement performance and distress trends.

This research details the methodologies employed in the PAVEAIR pavement inspection data retrieval and dataset organization, and further presents the results of a two-part analysis. First, rate of deterioration (ROD) of various pavement families were evaluated by fitting a linear regression to the pavement condition index (PCI). Then, historical distresses data were analyzed for various pavement families in the different climatic regions. Families were assigned with respect to climate, pavement structure (conventional asphalt or asphalt overlays), and branch type (apron, taxiway, and runway).

The regression results showed that pavements in the WF region have the highest ROD, followed by the pavements in the DNF region. In terms of branch type, in three of four climatic regions, aprons have the fastest rate of deterioration, followed by taxiways and runways, respectively. The distress analytics revealed that cracking type of distresses were the most common in all the regions regardless of the pavement family.

The results showed that climatic data alone were not adequate to characterize airfield pavement behavior due to the multivariate factors affecting pavement

deterioration. An accurate pavement and distress prediction modeling effort should at least include additional information on the structure and traffic level.

ACKNOWLEDGMENTS

I would take this opportunity to express my gratitude to Dr. Hasan Ozer for the guidance, and support he provided during this research project. Special thanks also go to Prof. Kamil Kaloush and Prof. Michael Mamlouk for their comments and suggestions. Additionally, I profoundly appreciate the Airport Cooperative Research Program's for providing sponsorship and expert resources throughout the conduct of the research. I specially acknowledge the help of David Brill, Scott Murrell, and Tim Parsons in collaborating to facilitate access to the databases used in this study.

I also want to thank the Mastercard foundation Scholars program for the unflinching support I have received throughout my college education. Last but not the least, my graduate studies would not have been possible without the affectionate encouragement of my family, and the community and belonginess of my colleagues.

TABLE OF CONTENTS

Page

CHAPTER Page

APPENDIX Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1. INTRODUCTION

1.1 Background

The Federal Aviation Administration (FAA) provides administrative responsibility and oversight of the United States (USA) national airport systems to ensure safe and efficient airport operations. Through its Airport Improvement Program (AIP), public-use airports are identified to be eligible for airports' planning, and development grants from the federal government (FAA, 2021). In its most recent congress narrative, the National Plan of Integrated Airport Systems (NPIAS) which assess and identify AIP eligible airports, classified airfield pavements' rehabilitation/reconstruction needs as the largest development category, accounting for an estimated 39 percent ($17 billion) of NPIAS funding needs (NPIAS, 2020). This amount highlights a 29 percent increase from what was estimated in previous report issued in 2019, reflecting the increase in reconstruction costs and the increasing need for rehabilitation at more airports. Unlike other categories, the increase in need for rehabilitation/reconstruction has seen a continuous uptrend over the years as demonstrated in Figure 1 (NPIAS, 2020). Therefore, there is a need for more robust and informed design, and maintenance and rehabilitation (M&R) practices for airfield pavements considering the uncertainties for available funds for future rehabilitation or reconstruction projects.

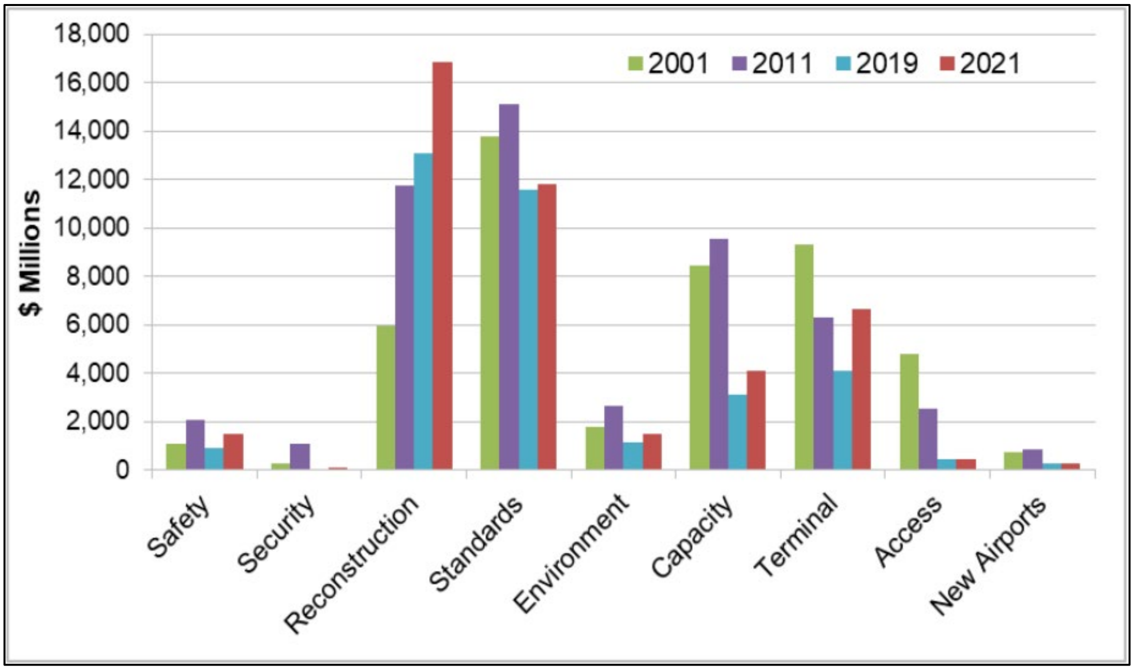


Figure 1. 5-Year Airports Development Costs by Category, FYs 2001–2021

Mechanistic based design methods have primarily been developed for highway pavement to address premature distresses and reduced uncertainty in the performance. These design methods sufficiently capture the extent to which climatic and traffic related factors contribute to the deterioration of pavements (Wu, 2005; Ullidtz et al. 2010). A notable mention is the American Association of State Highway and Transportation Officials (AASHTO) Mechanistic Empirical Pavement Design Guide (MEPDG). Mechanistic design approaches identify the extent of to which stress inducing factors affect pavement performance and then recommend a pavement structure that can sufficiently withstand such operational factors (Li, Xiao, Wang, Hall, & Qiu, 2011). Mechanistic models require a pavements operational factor such as; traffic, climate, pavement materials properties and structure, as inputs and then compute the pavements response to such factors to determine a sufficient design.

FAA's pavement design method evolved over the years from more empirical to include mechanistic components. FAA Rigid and Flexible Iterative Elastic Layered Design (FAARFIELD) is the FAA's standardized software for airfield pavement thickness design (AC 150/5320-6G, 2021). The software employs mechanistic-empirical techniques to determine pavement layers thicknesses based on the anticipated factors that will impact the infrastructure's performance. FAARFIELD uses layered elastic theory for flexible pavements, and three-dimensional finite element (3D-FE) theory for rigid pavements to computes the pavement materials' response to traffic. Based on the stress and strain response, the program determines the pavement layer thicknesses that will adequately accommodate the anticipated traffic. However, FAARFIELD does not explicit account for pavements response to climatic factors. For instance, the design procedure recommends that, pavement designers have recourse to local engineering and construction experience when there is concern for frost occurrence (AC 150/5320-6G, 2021).

The FAA's Pavement Management Programs (PMPs) provide objective and systematic procedural guidance to help establish facility policies, set priorities and schedules, allocate resources for pavement maintenance and rehabilitation (AC 150/5380-7B, 2014). An essential component of a PMP is the information regarding existing pavement structure and pavement condition. In 2011, the FAA launched a public web-based application, PAVEAIR, to assist organizations to evaluate, manage, and maintain their pavement networks (FAA PAVEAIR 3.5.1, 2017). In addition, the application hosts a data repository containing historic and current information about airport pavement construction, maintenance and management. Some of the essential information include pavement condition, inspection records, and M&R history. PAVEAIR has an in-built capability to predict future airfield pavement performance, expressed in terms of either Pavement Condition Index (PCI), Structural Condition Index (SCI) or Foreign Object Damage (FOD).

1.2 Problem Statement

The increasing trend in expenditure requirements for airfield pavements M&R necessitates the need for more robust and informed design, and maintenance and rehabilitation practices for airfield pavements. The PAVEAIR web-based public data repository has the potential to be a key resource in future development of airfield pavement's mechanistic design methods. The pavement surface condition and distresses data housed in the PAVEAIR are essential information for mechanistic models' validation. On the other hand, the content of this resource and the procedures in retrieving the data have not been sufficiently publicized. There is a need to develop systematic procedures to retrieve, restore and organize the airfield pavement data available in PAVEAIR online-public data repository. Once the data are retrieved and organized, analysis of pavement condition and distresses occurrence in different climatic regions, and for different pavement families can be explored.

1.3 Research Objective

The objective of this research is to study airfield pavements performance data from PAVEAIR to perform a preliminary investigation of pavement deterioration and distresses occurrence trends specific to certain climatic regions and/or pavement types. The work was therefore supported by the following specific objectives.

1. Review airfield pavement management programs to understand airfield pavement inventory and how performance is reported.
2. Review the literature to identify distresses that can be influenced by climate.
3. Review the data extraction methods from PAVEAIR and establish pavement condition and distress dataset for performance analyses.
4. Perform analyses to identify patterns specific to pavements in the same family (same branch, pavement type and climate).
5. Interpret the analyses results and make recommendations for future research.

CHAPTER 2. LITERATURE REVIEW

2.1 Pavement Distresses

Airfield pavements deteriorate under the combined impact of traffic, materials aging and environmental factors. This deterioration manifest in the occurrence of defects, otherwise known as distresses, in the pavement layers or the subgrade foundation. The rate of distress occurrence depends on the complex interaction of the various factors that influence the pavements performance. At any point in time, pavement asset managers rely on the knowledge of distresses present on their infrastructure to plan and make the right maintenance and rehabilitation (M&R) decisions to maintain safe traffic operation.

2.1.1 Airfield Pavements Performance Indicators

Performance indicators are widely adopted indices which quantify a pavement's performance. Thus, performance indicators provide asset managers with a metric on which M&R decisions can be based (Shahin, 1994; Sotil, & Kaloush, 2004). AASHTO defines pavement performance as the expectation of a pavement section to sufficiently provide the structural strength to support the expected traffic while maintaining safe surface rideability (AASHTO, 1993; Wu, 2015).

The pavement performance can be reduced into structural performance and functional performance which respectively refer to the pavement layers' ability to support the operating traffic, and how well the pavement facilitates convenient traffic operations. As a result, the variety of available performance indicators could either represent structural capacity, functional serviceability, or the overall pavement integrity. The FAA uses the Aircraft Classification Number - Pavement Classification Number (ACN – PCN) method as a structural index, airfield pavement roughness and skid resistance as the functional index, and PCI as a comprehensive metric for the overall pavement integrity (Shahin, 1994; AC 150/5320-12C, 1997; AC 150/5380-9, 2009).

Loose debris from deterioration pavements poses damaging risk on aircraft's ground movement. Thus, the FOD index is defined to account for existing pavement distresses that generate loose pavement pieces (www.faapaveair.faa.gov/Help). The index is measured on a scale of 0 to 100, with 100 being a perfect conditioned surface. FOD calculation is after the procedure outlined in ASTM D5340: Standard Test Method for Airport Pavement Condition Index Surveys (ASTM D5340-12, 2018), which is introduced in Section 2.1.3 below.

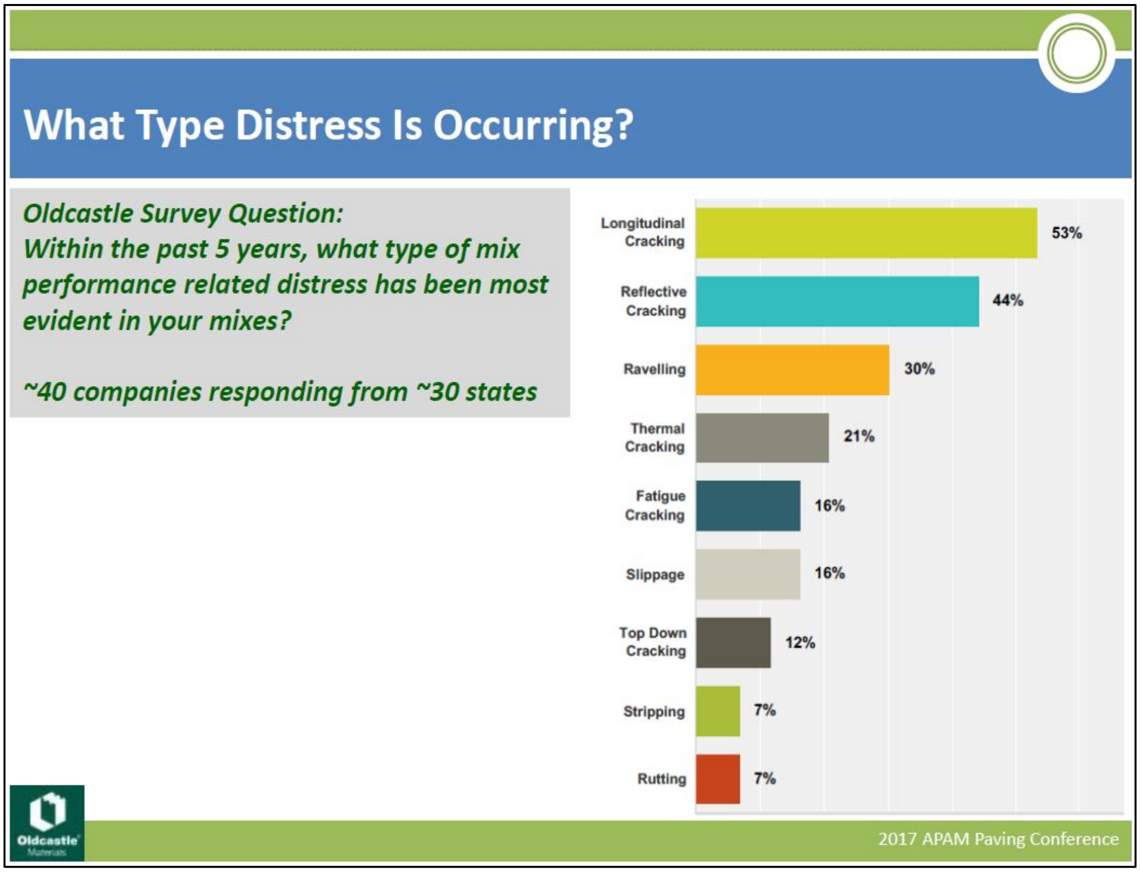
2.1.2 Critical Distresses

It is well known that pavement distresses occur under the combined effects of multiple factors. However, there are individual distresses which have been identified to result from specific pavement operational conditions. Distresses such as rutting, fatigue crack, PCC slab settlement, etc., have been known to result when the pavements structural capacity is inadequate to support the traffic loads. Similarly, occurrence of block cracks and PCC blow-ups are known to be prevalent under certain climatic conditions.

In this research, alligator cracking, joint reflective cracking, longitudinal cracking, raveling, rutting, and weathering data were retrieved and used in the distress occurrence analyses. These distresses have been widely studied due to their significance to most pavement operations. In a 2017 survey, Buchanan reported four of these distresses among the five most occurring distresses in thirty states around the continental USA as shown in Figure 2 below (Buchanan, 2017).

2.1.3 Pavement Condition Index (PCI)

The PCI is a comprehensive metric which is computed from pavement surface inspection. It measures pavement performance on a scale of 0 to 100, with 0 representing a completely failed pavement and 100 representing a pavement in perfect condition (Shahin, 1994). Surface condition is identified as “the most vital” information in a PMP (AC 150/5320-17A, 2014). That is because, the occurrence of various surface distresses provides a lead to infer the state of other performance characteristics. For instance, observable surface bleeding or polished aggregates will inform a surface with poor skid performance (low friction). Similarly, occurrence of severe rutting denotes inadequate structural capacity for the operating traffic loads.



What Type Distress Is Occurring?

Oldcastle Survey Question:
Within the past 5 years, what type of mix performance related distress has been most evident in your mixes?

~40 companies responding from ~30 states

Figure 2. Survey results for most occurring distresses in 30 states (Buchanan, 2017)

Condition inspections for PCI calculation are conducted according to specified guidelines to minimize the effect of subjective judgements. For instance, ASTM D5340*,* provides guidance to help engineers:

- identify distresses (images of typical distresses in AC or PCC are provided).
- denote unit of measure/extent of identified distresses (units could either be areal, linear, number, or undesignated).
- assign severity to identified distresses (indicate measure thresholds to denote as either low (L), medium (M), or high (H) severity).

- determine deduct value (DV) from distress type, severity level, and quantity measured.
- compute PCI.

The PCI calculation involves a methodology which normalize the different units of measures of the different distresses. For every distress identified and measured in an inspection, a deduct value is computed by the procedure provided in ASTM D5340 which is illustrated below.

Deduct Value (DV) Calculation

- The calculation begins with the computation of total quantities at each severity level for each distress identified. It must be noted that these computations are done for each pavement sample assigned during inspection.
- The density of the distresses at each severity level are then determined by expressing the total quantities as a percentage of the sample area.
- Then the DV for that sample is determined from the deduct curves provided in the Appendix of ASTM D5340-12, example of which is shown in Figure 3 below.

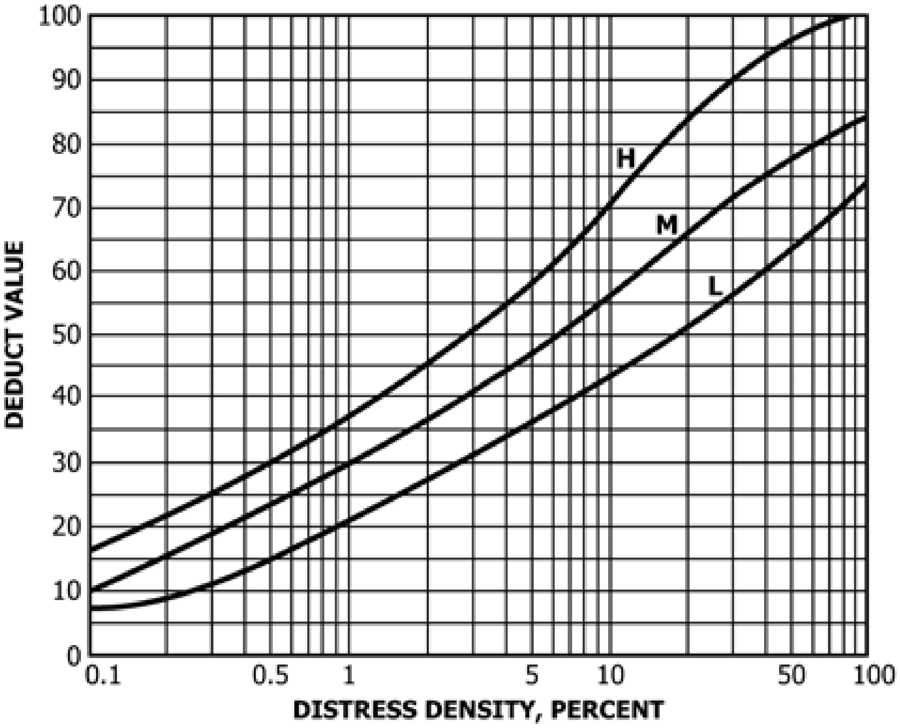


Figure 3. Alligator cracking deduct curves for airfield AC pavements.

ASTM D5340 prescribes a determination of a total deduct value (TDV) for each pavement sample, which is computed from the DV for the different distresses at the different severity levels. The TDV is further corrected to find the Corrected Deduct Value (CDV), which exclude all deducts less than 5. The sample deduct is then computed from Equation 2.1 below. A section DV is subsequently determined from the weighted average by area of the samples' CDV.

$$PCI = 100 - CDV \qquad \textbf{2.1}$$

From the methodology, DV therefore provides an objective measure which denote the significance of each observed distress in terms of its corresponding impact on pavement performance. PAVEAIR's in-built PCI calculation tool performs all DV and PCI calculations from the reported distress information. This study used the DV to investigate and compare the occurrence of the identified critical distress which have been documented and presented in Chapter 6.

2.2 Pavement Management Programs (PMPs)

In the recent decades, experts in the field of pavement engineering have been making strides to establish more objective procedures in making decisions concerning pavement design and operation. A notable milestone has been the advent of mechanistic-empirical design methodologies which replaces purely experienced-based (empirical) design methods (Li, Xiao, Wang, Hall, & Qiu, 2011). Likewise, airport managers, pavement engineers and asset managers advocate for deliberate and purposeful schemes to facilitate the decision-making process involved in implementing pavement M&R projects. These schemes are generally referred to pavement management programs (PMP). A PMP in effect provides a systematic and robust method for identifying maintenance and repair (M&R) needs, while highlighting work priorities and providing a framework for scheduling maintenance activities to optimize cost (Shahin, 2005; AC 150/5380-7B, 2014). The PMP concept inherently considers the life cycle cost to choose from possible M&R alternatives. This attribute is illustrated in Figure 4 which shows the pavement condition life cycle as described by Shahin (2005). A nonlinear rate of deterioration (ROD) associated with pavement condition over time is illustrated. This gives insight into deciding whether implementing a given maintenance would be worth the investment. For instance, performing maintenance on ‘very poor’ pavement to restore it to a ‘fair’ condition will only be sustained for a very short time.

In order to help airport mangers to implement PMPs, the FAA clearly outlines the components of PMP as enumerated in the sections below. It further requires public use airports to have an effective PMP to be eligible for federal funding.

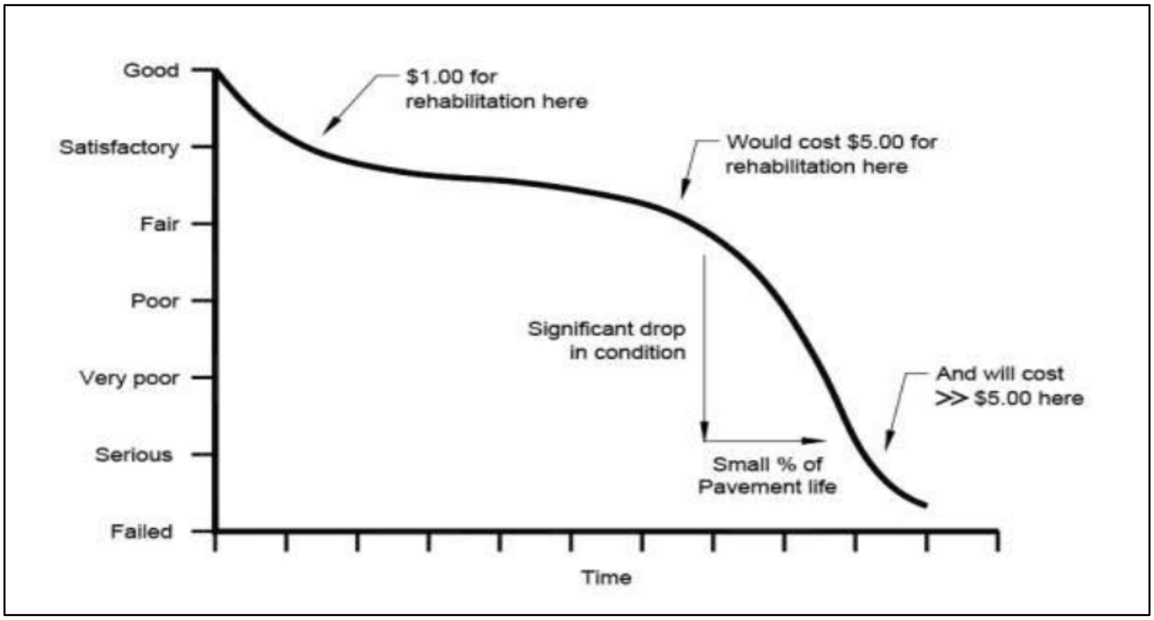


Figure 4. Concept of Pavement Condition Life Cycle (Shahin, 2005)

2.2.1 Database

Data about existing pavements serves as an essential component that provide the base to help stakeholders make informed decisions to keep airfield pavements in serviceable conditions (AC 150/5380-7B, 2014). Information of the pavements' inventory, inspection records, history of M&R, and traffic data provide airfield pavement engineers and asset managers the tools to learn firsthand to identify the actual field performance of different structural conditions and the role of various M&R practices in ensuring the safety and serviceability of the pavements.

2.2.1.1 Pavement Inventory Definitions

Data on existing pavement inventory; the areal locations, dimensions, pavement types and year of pavement construction are essential in pavement asset management and M&R planning. Airfield pavement inventories can be defined in a hierarchy of area as either networks, branches, sections, or samples. Shahin defined pavement networks as logical groupings of pavements for M&R management (Shahin, 1994). Network assignments are based on facility types, funding sources, minimum operational standards, and geographical location. For instance, an airport may designate its pavements assets as two networks, where airfields are defined as a separate network and roads and parking lots, as another network. The next level in the inventory hierarchy are branches, which are parts of the network having specific use. For instance, airfield runways, which are designed for the purpose of aircraft landings and take-offs is a unique branch from airfield aprons, which are spaces designed for aircraft parking. Other branches include taxiways, helipads and among others. Next in the inventory hierarchy are sections. Sections are subdivisions of branches, and they refer to contiguous pavement area with similar *performance characteristics*. Thus, sections are thought of as “the smallest management unit” (Shahin, 2005). During inspections, sections could be further divided into samples with regular sizes. A sample size of 5000 ± 2000 square feet (sq-ft) is recommended for asphalt concrete (AC) surfaced pavements and sample size of 20 ± 8 slabs is recommended for Portland cement concrete (PCC) surfaced pavements with joints spaced not greater than 25 ft (ASTM D5340-12, 2018). In the database, inspection results, including identified distresses, are recorded for samples from which certain performance indicator variable(s) are computed for the section.

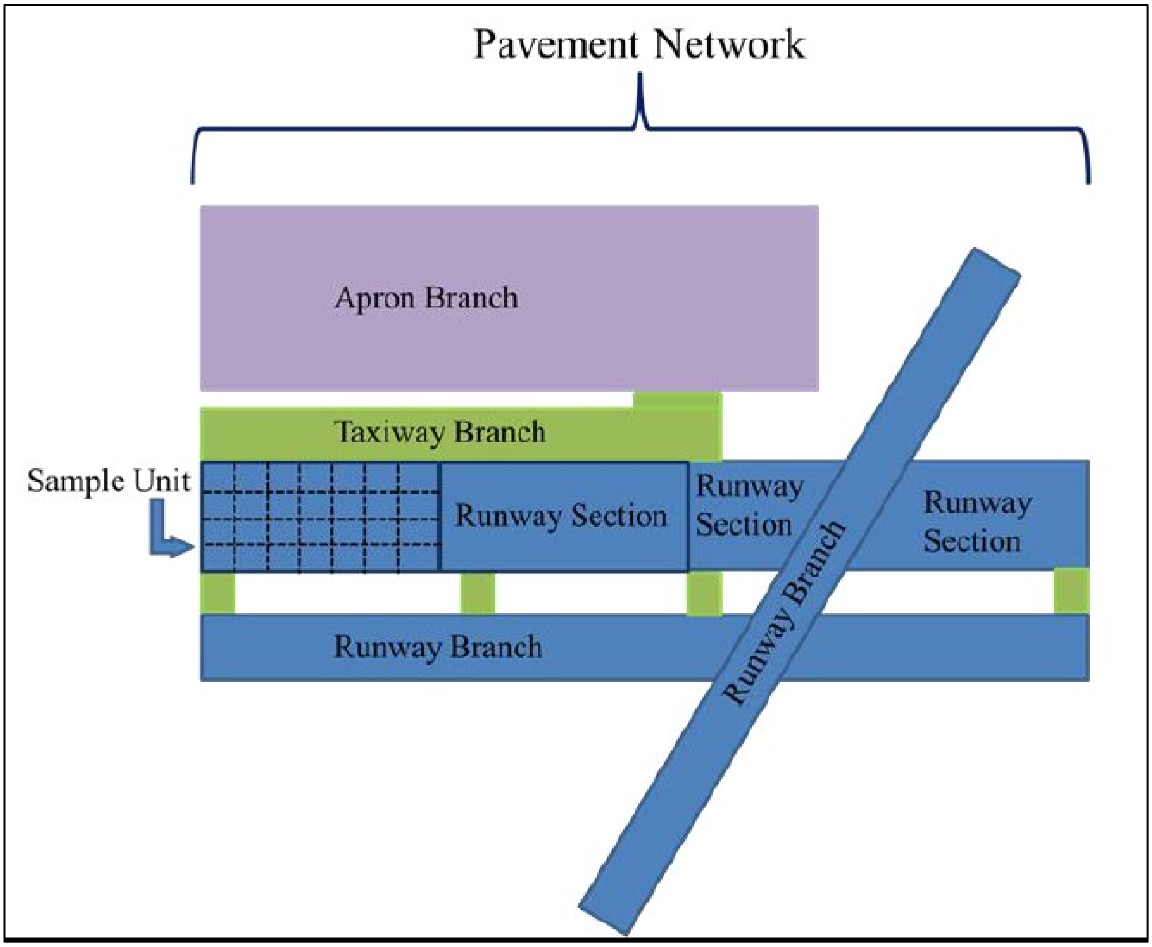


Figure 5. Airfield Pavement Inventory Hierarchy (Sahagun, 2014)

2.2.1.2 Pavement Inspection

Airfield pavement inspections is the medium through which airfield mangers identify M&R needs on their assets. Various pavement performance characteristics including roughness, surface conditions (distresses), skid characteristics (friction), and structural capacity are assessed during the inspections. Due to the importance attributed to airfield pavements, the FAA recommends a detailed annual pavement inspection.

Structural capacity refers to the load carrying capacity of the pavement. It can be evaluated by collecting field cores or by employing non-destructive test (NDT) methods.

The FAA reports airfield pavement information using the Aircraft Classification Number - Pavement Classification Number (ACN – PCN) method developed by the International Civil Aviation Organization (ICAO) in 1977 (AC 150/5335-5C, 2014). The method uniquely assigns an ACN to denote the relative effect of an aircraft, of a given weight and configuration, on a pavement structure for a “specified standard subgrade strength”. For flexible pavements, the load-carrying capacity, or PCN, is determined based on the (HMA/aggregates) CBR, whiles the k-value serves as the PCN input for rigid pavements. The procedures for computing the ACN and PCN are detailed elsewhere (AC 150/5335-5C, 2014).

Surface condition is identified as “the most vital” information in a PMP (AC 150/5320-17A, 2014). That is because, the occurrence of various surface distresses provides a lead to inferring the state of other performance characteristics. For instance, observable surface bleeding or polished aggregates will inform a surface with poor skid performance (low friction). Similarly, occurrence of severe rutting denotes inadequate structural capacity for the operating traffic loads. Condition inspections are usually conducted according to specified guidelines to minimize the effect of subjective judgements. For instance, ASTM D5340: *Standard Test Method for Airport Pavement Condition Index Surveys,* provides guidance to help engineers to: (ASTM D5340-12, 2018).

- identify distresses (images of typical distresses in AC or PCC are provided).

- denote unit of measure/extent of identified distresses (units could either be areal, linear, number, or undesignated).
- assign severity to identified distresses (indicate measure thresholds to denote as either low (L), medium (M), or high (H) severity).
- compute PCI.

2.3 Environmental Factors Affecting Pavement Performance

Pavement assets are expected to be in good and operable conditions in all climatic conditions in various seasons of the year. Climatic conditions, however, may have a very significant effect on pavements ability to support traffic loads. For instance, in-situ soils which serves as subgrade for majority pavement, softens and weakens in a moist state, leading to excessive subgrade consolidation and settlements. The role of climatic factors couples with traffic, material characteristics, construction quality, and M&R practices to drive a pavement's deterioration characteristics throughout the pavement's life (Llopis-Castelló, García-Segura, Montalbán-Domingo, Sanz-Benlloch, & Pellicer, 2020; Li, Mills, & McNeil, 2011; Meihaus, 2013). The multi – factor (variable) nature of pavement deterioration presents experts a very challenging reality to adequately pinpoint the extent to which each factor contributes (Barua, Zou, et al, 2020). Notably, range of temperature, precipitation, and freeze-thaw cycles have been identified to significantly influence the long-term performance of a pavement (Haas, 2001; Tighe et al, 2006). On exposure to certain degrees and intensities of these factors, a pavement's integrity can be compromised in some of the ways discussed below.

2.3.1 Temperature

Changes in temperature influences the deterioration characteristics in both rigid and flexible pavements. In flexible pavements, high and low temperatures change the stiffness of the hot mix asphalt (HMA) binder. HMA binder have been known to exhibit very stiff and brittle properties in low temperatures, resulting in high occurrence of cracking in pavements subjected to those temperatures. Additionally, repeated daily temperature fluctuation cycles induce stress and strain buildups which leads to irrecoverable deformations showing up as thermal fatigue cracks (Al-Qadi, Hassan, & Elseifi, 2005). In flexible pavement design, engineers choose binder grades which have performance tolerance according to the typical temperatures in the project's vicinity.

In rigid pavements, thermal induced stresses result in a tendency (force) for expansion and contraction. This tendency might cause blow-ups as in the case of uncracked-continuously designed PCC pavements. In situations of differential temperature within the depth of a pavement structure, differential expansive or contractive forces are induced which cause the pavement to curl up or downwards. Joints are usually introduced in PCC pavements, every 3.5m to 6m. to accommodate the expansion and contraction tendencies (AASHTO 1993).

2.3.2 Precipitations and Moisture Infiltration

The strength property of subgrade and unbound base materials, which form the foundation for majority of pavements, is very susceptible to its moisture content. Poor drainage and pavements surface joints, and cracks serves as the main means for moisture infiltration into the subsurface pavement structures. Moisture in the pavement accelerate the pavement deterioration process, which lead to development of more surface defects that allow more moisture to infiltrate the pavement (Boudreau, Christopher, & Schwartz, 2006; Meihaus, 2013).

2.4 Airfield Pavement Design Standard

Pavements are designed with expectation for the asset to sufficiently accommodate the anticipated design traffic while providing safe vehicle operation conditions and maintaining acceptable riding quality. Therefore, pavement designers are tasked to holistically account for the interaction of all environmental conditions, traffic characteristics, and material properties to achieved acceptable designs at reasonable economic cost (AASHTO, 1993; AC/ /5320-6G; Boudreau, Christopher, & Schwartz, 2006). The FAA Rigid and Flexible Iterative Elastic Layered Design (FAARFIELD) is the FAA's standardized software for airfield pavement thickness design. This mechanistic empirical software takes the aircraft traffic characteristics, and the pavement materials and structural properties as inputs to determine the pavement's response, and subsequently determine layer thickness(es) which will sufficiently provide the structural capacity required to support the design traffic. The methodology is iterative in which an initial design thickness is chosen.

2.4.1 Traffic Consideration

FAARFIELD considers the impact of the anticipated traffic mix and the typical loading conditions. The traffic mix refer to all aircrafts and non-aircraft vehicles which are expected to regularly operate on the pavement facility. Important factors of the traffic mix which influence the pavement's mechanical response (that is stresses and strains leading to damage) include the load magnitudes, aircraft gear type and configurations, and the tire pressure (AC 150/5320-6G). FAARFIELD has an in-built *Aircraft Library* which house many civil and military aircrafts and their manufacturers-recommended gross operating weights and load distribution characteristics to help users choose from. The software further allow user to create 'User Defined Aircraft' for vehicles which are nonexistent in the aircraft library (AC 150/5320-6G).

Additionally, the traffic volume is essential to determine the cumulative impact of all traffic that operate on the airfield pavement facility. The total aircraft departures are typically used in design considerations due to the significantly heavy weights at departures (prior to fuel consumption). The total number of departures over a pavement's life can be computed from the Equation 2.1 below.

$$N = N_A \times L \times \left(\frac{r \times L}{200}\right) \qquad 2.2$$

Where N is total departures over pavement lifetime, N_A is annual number of departures, r is the growth rate (percent), and L is the design life

2.4.2 Pavement Materials and Structure Consideration

The mechanical response a pavement generate depends on the properties of materials in its structural layers. Depending on an initial structural layer thickness(es), moduli, and Poisson's ratio, FAARFIELD computes the pavements response using layered elastic theory for flexible pavement cases, and three-dimensional finite element (3D-FE) theory for rigid pavements.

Flexible pavement design module determines the maximum vertical strain on top of the subgrade and the maximum horizontal strain in all asphaltic layers. Thus, according to the design criteria, a structural composition which limit the vertical strain on top of the subgrade to prevent rutting failure or limit horizontal strain to guard against cracking in the asphalt layer(s).

2.4.3 Environmental Considerations

The mechanical impact of the various climatic factors which impact pavement performance are not explicitly captured in the FAARFIELD methodology. In order to account for climatic effects, recommendations are made on either the material types to use in the design, or to alter typical values of the mechanical properties of materials. For instance, it is recommended to resort to local engineering and construction experience when there is concern for frost occurrence.

CHAPTER 3. DATA SOURCES

In the effort to identify the role of climate in pavement deterioration, Tim Parsons of Applied Research Associates (ARA) provided eighty-four (84) airfield pavement inspection databases. Fifty-six (56) of these databases were Structured Query Language (SQL) backup files and the other twenty-eight (28) were MicroPaver files. The data in the backup files could not be used for the analyses presented in this document. This was because the type of conditions, either FOD, PCI or SCI, were not specified in those databases. FAA PAVEAIR web application was used to restore pavement surface condition and distress records from the Micropaver files. Additionally, historical climate data from the various airfields were obtained from the National Oceanic and Atmospheric Administration's National Centers for Environmental Information (NCEI-NOAA) online public database to identify how they correlate with the performance trends. Due to limited publicly available information on working with PAVEAIR, the sections below detail the procedures involved in extracting and restoring inspection databases.

3.1 Pavement Inspection Databases from PAVEAIR and Database Schema

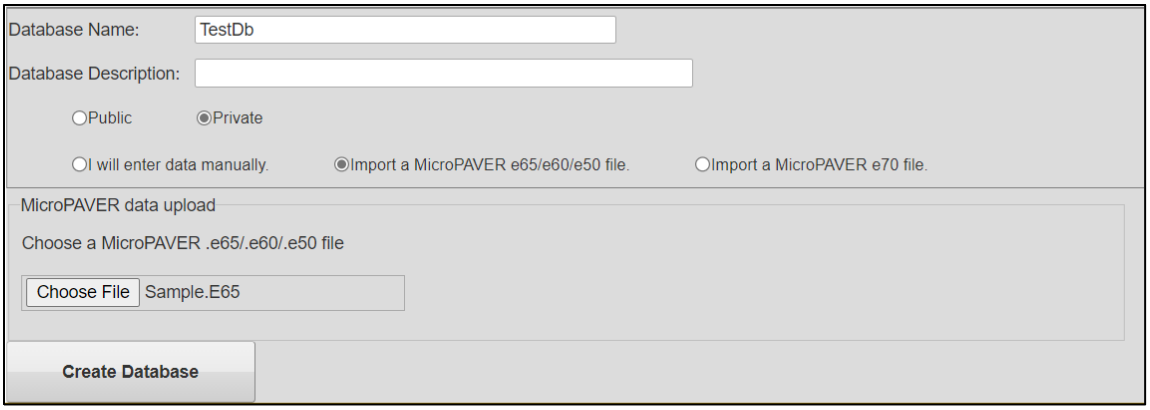
The FAA PAVEAIR web application contains many publicly shared pavement inspection records from airports around the continental USA. Additionally, PAVEAIR has an in-built tool for converting conventional MicroPaver files (in *.eX formats) ,which contain inspection records, to XML formats which can subsequently be restored into database management programs. The procedure can be summarized as

- Importing database (MicroPaver file) into PAVEAIR
- Exporting database (XML) from PAVEAIR

- Restoring XML into SQL
- Query database to organize needed data.

3.1.1 Importing MicroPaver inspection Database into PAVEAIR

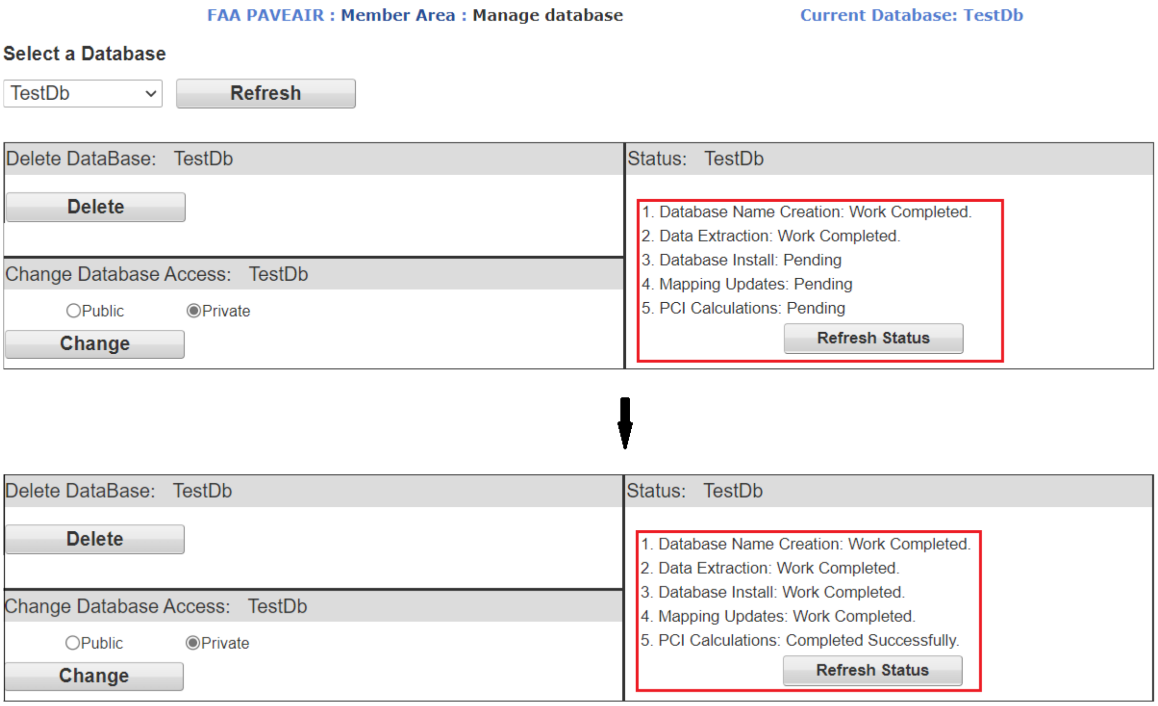
Registered PAVEAIR users can import MicroPaver files using the create database tool in the *Member Area*. Following the outline of Figure 6, the sixteen databases were imported by specifying the MicroPaver file format and then selecting the given data file. After the file importation, it should be noted that PAVEAIR performs a background process to compute the PCI, SCI and FOD from the distress information in the inspection record.



Database Name: TestDb
Database Description:
○ Public ● Private
○ I will enter data manually. ● Import a MicroPAVER e65/e60/e50 file. ○ Import a MicroPAVER e70 file.
MicroPAVER data upload
Choose a MicroPAVER .e65/.e60/.e50 file
Choose File Sample.E65

Figure 6. Importing MicroPaver into PAVEAIR

To make sure all processes were completed, each file importation status was checked before proceeding to export the data. Figure 7 illustrate the upload status. The created database can be selected from the *Home* tab.



1. Database Name Creation: Work Completed.
2. Data Extraction: Work Completed.
3. Database Install: Pending
4. Mapping Updates: Pending
5. PCI Calculations: Pending

1. Database Name Creation: Work Completed.
2. Data Extraction: Work Completed.
3. Database Install: Work Completed.
4. Mapping Updates: Work Completed.
5. PCI Calculations: Completed Successfully.

Figure 7. PAVEAIR database importation status

3.1.2 Exporting Database from PAVEAIR

PAVEAIR *Tools* module provide the capability for users to save an XML format of the currently selected database. The export feature is shown in Figure 8 below. The imported databases were exported into XML formats, and subsequently converted into xml formats for easy data handling and processing.

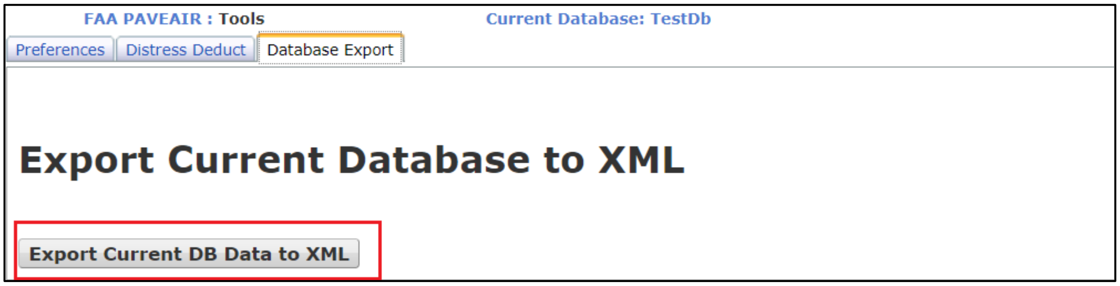


Figure 8. Exporting Database from PAVEAIR

3.1.3 Pavement Inspection Database

Data quality is very essential to the usefulness of all data analyses results. The data used in this research have been recorded from carefully conducted airfields inspections. As such, the records in the retrieved databases were taken to be actual airfield pavements performance, unless where obvious mistakes such as assignment of wrong units to recorded distresses are noticed. Additionally, accurate data querying from the restored SQL databases critically depended on the understanding of relations between the different tables in the databases. In this section, details of the schema for the restored databases are provided.

3.1.3.1 Inspection Database Schema

Each database consists of seventeen (17) tables with unique links. The pavement condition data and distresses records were queried from eight of the tables shown in Figure 9, and a description of the content of those tables are presented in Table 1 below.

Table 1. PAVEAIR database tables descriptions

Table Name	Description of Content
Network	Contains the names and ID (NetworkID) for all the pavement networks contained in the database. Each database contains information for one or mode networks.
Branch	Contains the use (BranchUse) and ID (BranchID) of all the pavement branches contained in the database. It is linked to the network table through the NetworkID which associate all branches to their respective networks.
Section	Assigns unique IDs (SectionID) to all the section and link the sections to their respective branches through the BranchID. It details the pavement geometry, and surface materials type. It also serves as a reference unit for inspection activities and performance information.
Inspection	InspectionID uniquely identify all inspection activities which's records make up the database. It contains the two primary details for every inspection record, which section was inspected and when was the inspection.
Samples	The primary key, SampleID uniquely identify all samples. The table is linked to the inspection table such that every sample can be traced to it location (sample) and when it was created.
Distress	The table uniquely identify all instances of distress (DistressID), indicates the distress name, quantity, and severity and link each instance to the sample which showed that distress.
SamplesDeduct	This table is created from the PCI calculation tool in PAVEAIR. It assigns the computed deduct to the various samples.
Condition	This is also a derivative of the PCI calculation tool in PAVEAIR, which contains the computed sections' PCI computed after ASTM 5340's prescription.

An additional illustration of the data query has been presented in the methodology chapter.

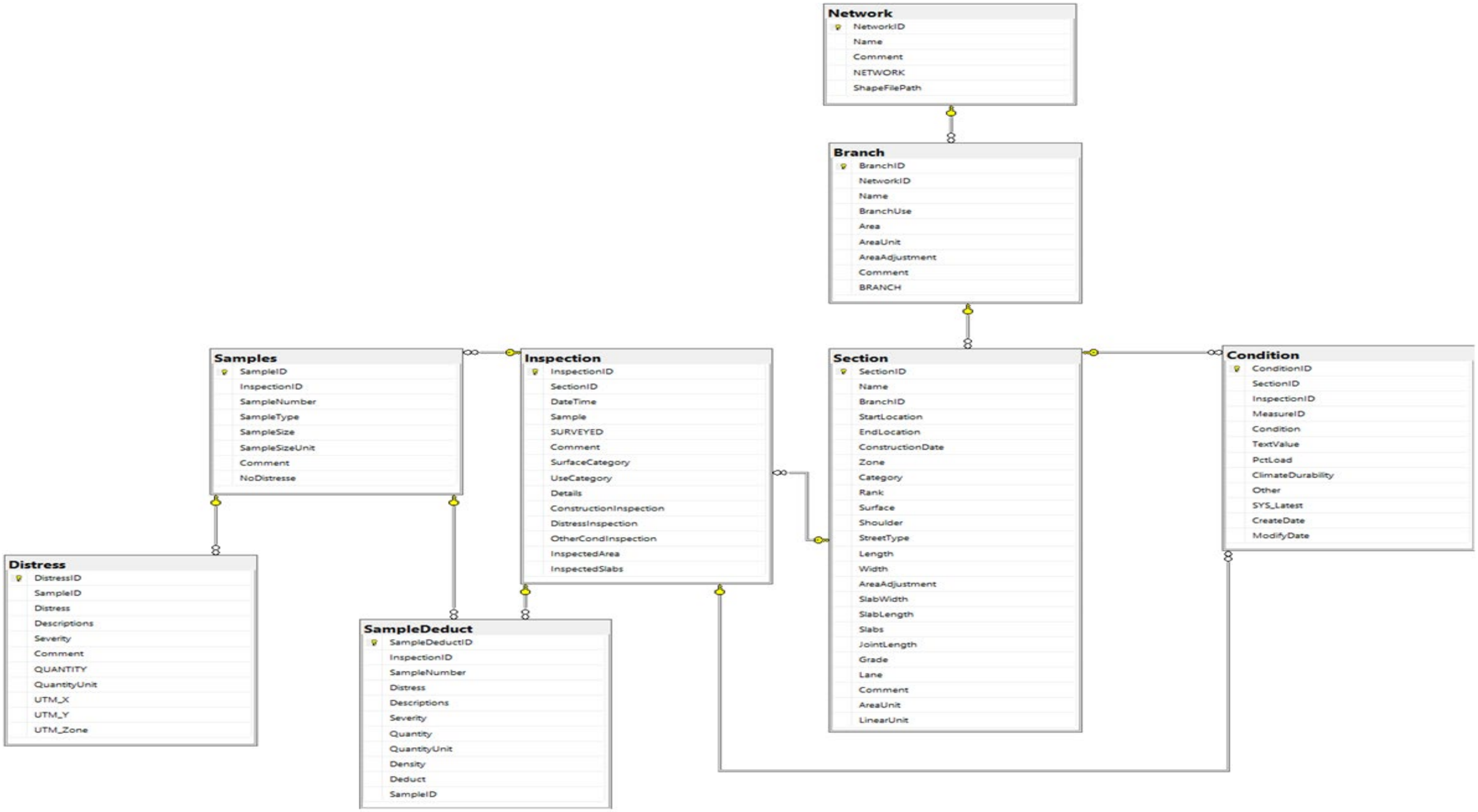


Figure 9. Tables schema used in PCI and distress datasets development

3.2 Airport Climatic Data

Temperature, freeze-thaw cycles, precipitation, and subsurface moisture condition are among the most notable factors that impact how pavements perform (Li, Mills, & McNeil, 2011). The climate records were retrieved from the Global Surface Summary of the Day (GSOD) dataset of the NCEI-NOAA online public platform (www.ncei.noaa.gov). The NCEI-NOAA platform hosts an extensive archive of climate, coastal, oceanographic, and geophysical data. The GSOD contains daily land surface weather observations obtained from the United States Air Force (USAF) Climatology Center.

The climate parameters extracted included minimum, maximum, and average temperatures as well as precipitation. The data were gathered from stations at the various airfields with available data. The numbers of airfields with available data in each climatic region are as follows: 10 airfields in the DF region, 21 airfields in the DNF region, 20 airfields in the WF region, and 10 airfields in the WNF region. Data included daily records for the past five full years (2016–2020).

CHAPTER 4. METHODOLOGY

In this chapter, details of the data processing, methods and techniques employed in this research effort are presented. These processes involved cleaning and organizing the restored pavement data into families and performing pavement performance analyses to identify familial and regional trends in distresses occurrence.

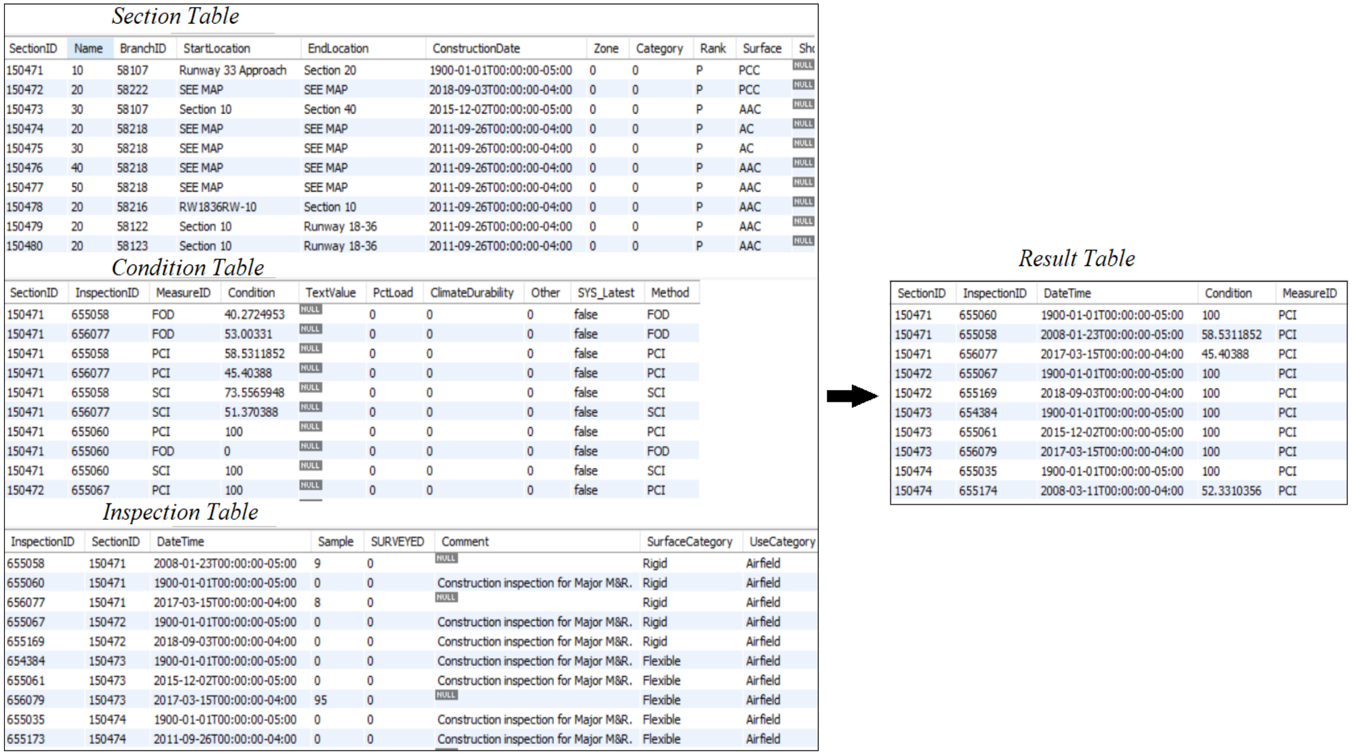
4.1 Data Organization

4.1.1 Pavement Condition Dataset Development

The pavement performance data were retrieved through MySQL. For each section in the database, the PAVEAIR *PCI calculation tool* compute the PCI from the reported distresses according to the method proposed in ASTM D5340. The pavement age at the time of inspection was vital to develop PCI-Age performance curves. Therefore, the date of inspection used for each PCI computation for that section had to be linked to that PCI record. An SQL join-statement provides that possibility, in which the Section table, condition table and the inspection tables were joined together. The tables joining is illustrated in Figure 10.

The age was then determined as the number of years since the last major M&R. This was decided on the assumption that there will be perfect condition restoration (that is PCI restored to 100) after a major M&R. It should also be noted that the pavement age was restarted at 0, whenever the PCI record was restored to 100.

Other key data selection criteria were the selection of only PCI records from the condition table as seen in the result table in Figure 10below. Also, the data were selected for sections with primary use functionality and that is, assigned a rank of ‘P’.



Section Table

SectionID	Name	BranchID	StartLocation	EndLocation	ConstructionDate	Zone	Category	Rank	Surface	Sh
150471	10	58107	Runway 33 Approach	Section 20	1900-01-01T00:00:00-05:00	0	0	P	PCC	NULL
150472	20	58222	SEE MAP	SEE MAP	2018-09-03T00:00:00-04:00	0	0	P	PCC	NULL
150473	30	58107	Section 10	Section 40	2015-12-02T00:00:00-05:00	0	0	P	AAC	NULL
150474	20	58218	SEE MAP	SEE MAP	2011-09-26T00:00:00-04:00	0	0	P	AC	NULL
150475	30	58218	SEE MAP	SEE MAP	2011-09-26T00:00:00-04:00	0	0	P	AC	NULL
150476	40	58218	SEE MAP	SEE MAP	2011-09-26T00:00:00-04:00	0	0	P	AAC	NULL
150477	50	58218	SEE MAP	SEE MAP	2011-09-26T00:00:00-04:00	0	0	P	AAC	NULL
150478	20	58216	RW1836RW-10	Section 10	2011-09-26T00:00:00-04:00	0	0	P	AAC	NULL
150479	20	58122	Section 10	Runway 18-36	2011-09-26T00:00:00-04:00	0	0	P	AAC	NULL
150480	20	58123	Section 10	Runway 18-36	2011-09-26T00:00:00-04:00	0	0	P	AAC	NULL

Condition Table

SectionID	InspectionID	MeasureID	Condition	TextValue	PctLoad	ClimateDurability	Other	SYS_Latest	Method
150471	655058	FOD	40.2724953	NULL	0	0	0	false	FOD
150471	656077	FOD	53.00331	NULL	0	0	0	false	FOD
150471	655058	PCI	58.5311852	NULL	0	0	0	false	PCI
150471	656077	PCI	45.40388	NULL	0	0	0	false	PCI
150471	655058	SCI	73.5565948	NULL	0	0	0	false	SCI
150471	656077	SCI	51.370388	NULL	0	0	0	false	SCI
150471	655060	PCI	100	NULL	0	0	0	false	PCI
150471	655060	FOD	0	NULL	0	0	0	false	FOD
150471	655060	SCI	100	NULL	0	0	0	false	SCI
150472	655067	PCI	100	NULL	0	0	0	false	PCI

Inspection Table

InspectionID	SectionID	DateTime	Sample	SURVEYED	Comment	SurfaceCategory	UseCategory
655058	150471	2008-01-23T00:00:00-05:00	9	0	NULL	Rigid	Airfield
655060	150471	1900-01-01T00:00:00-05:00	0	0	Construction inspection for Major M&R.	Rigid	Airfield
656077	150471	2017-03-15T00:00:00-04:00	8	0	NULL	Rigid	Airfield
655067	150472	1900-01-01T00:00:00-05:00	0	0	Construction inspection for Major M&R.	Rigid	Airfield
655169	150472	2018-09-03T00:00:00-04:00	0	0	Construction inspection for Major M&R.	Rigid	Airfield
654384	150473	1900-01-01T00:00:00-05:00	0	0	Construction inspection for Major M&R.	Flexible	Airfield
655061	150473	2015-12-02T00:00:00-05:00	0	0	Construction inspection for Major M&R.	Flexible	Airfield
656079	150473	2017-03-15T00:00:00-04:00	95	0	NULL	Flexible	Airfield
655035	150474	1900-01-01T00:00:00-05:00	0	0	Construction inspection for Major M&R.	Flexible	Airfield
655173	150474	2011-09-26T00:00:00-04:00	0	0	Construction inspection for Major M&R.	Flexible	Airfield

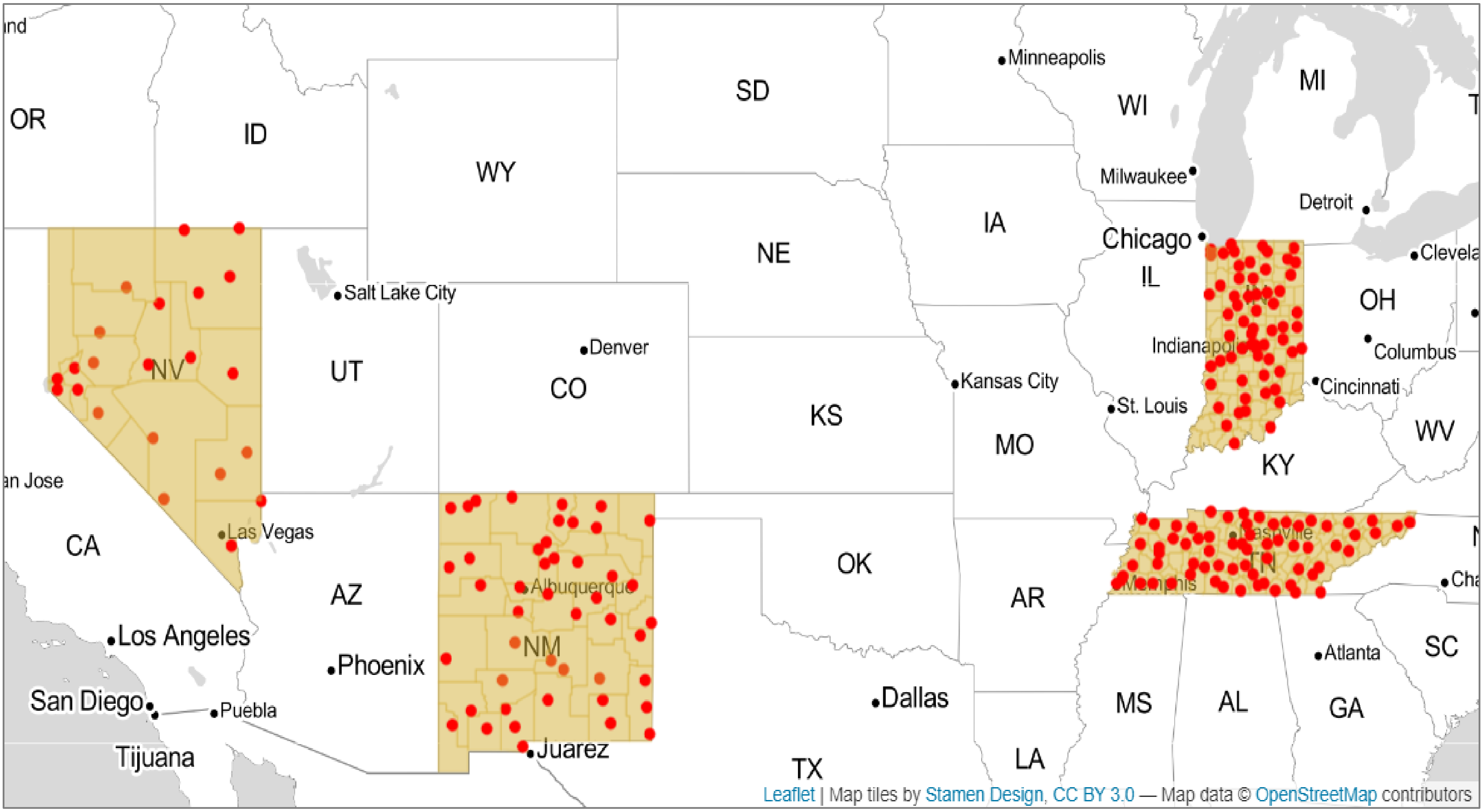
Result Table

SectionID	InspectionID	DateTime	Condition	MeasureID
150471	655060	1900-01-01T00:00:00-05:00	100	PCI
150471	655058	2008-01-23T00:00:00-05:00	58.5311852	PCI
150471	656077	2017-03-15T00:00:00-04:00	45.40388	PCI
150472	655067	1900-01-01T00:00:00-05:00	100	PCI
150472	655169	2018-09-03T00:00:00-04:00	100	PCI
150473	654384	1900-01-01T00:00:00-05:00	100	PCI
150473	655061	2015-12-02T00:00:00-05:00	100	PCI
150473	656079	2017-03-15T00:00:00-04:00	100	PCI
150474	655035	1900-01-01T00:00:00-05:00	100	PCI
150474	655174	2008-03-11T00:00:00-04:00	52.3310356	PCI

Figure 10. Joining Section information from different Tables

The data were cleaned up to get rid of anomalous data entries. A common anomaly is a negative (-1) condition index, which is the default value PAVEAIR assign to sections when an error is detected in the distress data. Following FAA's recommendation that a minimum of one (1) thorough inspection be conducted for airfield pavements every five years, sections with consecutive condition records that are more than ten years apart were excluded. That is to assume that, at least two inspection records are missing from that same section. Additionally, only pavement sections with a minimum of three PCI records in sequence were included in the organized dataset. The consecutive sequence of data is critical to capture the clear deterioration patterns of each section. A sequence of PCI records was defined as PCI values recorded after a major M&R up to just when another major M&R was performed (PCI restored to 100).

Out of the 6,800 instances of PCI records, 1,900 records passed the cleaning criteria mentioned above. These remaining data were organized into pavement family datasets. The datasets contained pavement condition information from 197 airfields networks from four states, one in each of the climatic regions across the United States. The selected airfields in their respective states are shown in Figure 11.



Leaflet | Map tiles by Stamen Design, CC BY 3.0 — Map data © OpenStreetMap contributors

Figure 11. Airfields with condition data in the four climatic regions

The statistics of the airfields with condition data are as follows: Nevada represents the DF region with 22 airfields. New Mexico represents the DNF region with 46 airfields. Indiana represents the WF region with 63 airfields. Tennessee represents the WNF region with 66 airfields. Additionally, Table 1 summarizes the families and their number of sections with valid condition data.

Table 2. Number of Sections with Valid Data in Each Climatic Region

		Number of Sections				**Total**	
Surf. Type	**Branch**	**DF**	**DNF**	**WF**	**WNF**	**Total**	**Cum. Total**
AAC	**Apron**	1	16	18	29	**64**	**280**
	Runway	12	28	25	21	**86**	
	Taxiway	3	29	77	21	**130**	
AC	**Apron**	9	44	25	11	**89**	**340**
	Runway	14	24	12	8	**58**	
	Taxiway	18	55	97	23	**193**	
Total		**54**	**57**	**196**	**254**	**620**	

4.1.2 Distress Dataset Development

In addition, recorded distress information was retrieved to understand occurrence characteristics of the critical distresses identified. Distresses in the database were recorded in terms of severity and measured quantities. These records are not directly comparable due to the differences in the scales of distress unit. Therefore, the DV for the occurring critical distresses were retrieved and used in the distress analytics to account for severity level extent. That is, DV takes into account the type, severity, and density of a given distress such that the DV denotes how that distress detract from the pavement condition. For instance, a high-severity rut with a 10% density could be more damaging than a high-severity weathering with a 90% density.

4.1.3 Climate Data Processing

The climate data used in this research effort were gathered from NCEI-NOAA database reported for weather stations at the various airports. The data in extracted included daily minimum, average and maximum temperatures, and daily precipitation. At each airport, monthly maximum, monthly minimum and average monthly temperatures were computed from the five years records period (2016-2020). Additionally, standard deviations of average daily temperature within each month were also computed at all airports. The standard deviation denotes the spread of the average daily temperature around the average monthly temperatures. This information is directly corresponded to the range of temperature within every month, which is a significant parameter that affect pavement performance.

Furthermore, the freezing index (FI), which is a metric for determining the severity of winter and freeze-thaw cycles, was computed from the extracted data using Equation 4.1 (Xiaoqing et. al, 2016). Furthermore, the Thornthwaite Moisture Index (TMI) was computed from Equation 4.2 to represent the relative aridity or humidity of soil (12). However, the precipitation records for stations at most airfields in the study were missing in the GSOD database. The TMI was therefore not used in the analyses.

$$FI = \sum_{i}^{n} (32 - T_i) \qquad 4.1$$

where T_i (^{o}F) is average daily temperatures on days below freezing, n is number of days with temperatures below freezing.

$$TMI = 75\left(\frac{P}{PE} - 1\right) + 10 \qquad 4.2$$

where P (cm) is average monthly precipitation, PE (cm) is potential evapotranspiration.

4.2 Pavement Performance Analyses

Descriptive analytics was performed to identify significant trends that stood out for any given pavement family. The analytics was performed by studying PCI progression with age. The roles of climate and traffic characteristics in airfield pavement deterioration were studied from the observable performance differences across the different pavement families.

4.2.1 Performance Clustering

The PCI-Age relation is an essential performance monitor for airfield pavement sections. As such, the performance trends for all the pavement section were generated for the different families using R-Studio. Figure 9 shows the typical PCI-Age plots developed for AAC runways in Indiana. The individual sections are identified on the plot by the airfield name and the SectionID.

These visuals revealed apparent patterns in the runway sections performance. Performance clusters were statistically defined such that, rapidly and slowly deteriorating runway sections were grouped in distinct clusters. In all the families, two or three cluster categories were assigned based on the observable patterns. These categories differentiated between fast, moderate, and slow deteriorating sections as were visually identified. It should be noted that for families where no distinctive clusters were observed, the data was retained non-clustered. The cluster trends also revealed that most of the sections at the same airport have very identical performance as seen from Figure

12. The clusters plots for seven additional families, which showed very distinctive performance trends between fast and slow deteriorating sections are presented in Appendix A to highlight difference in performance within the same families.

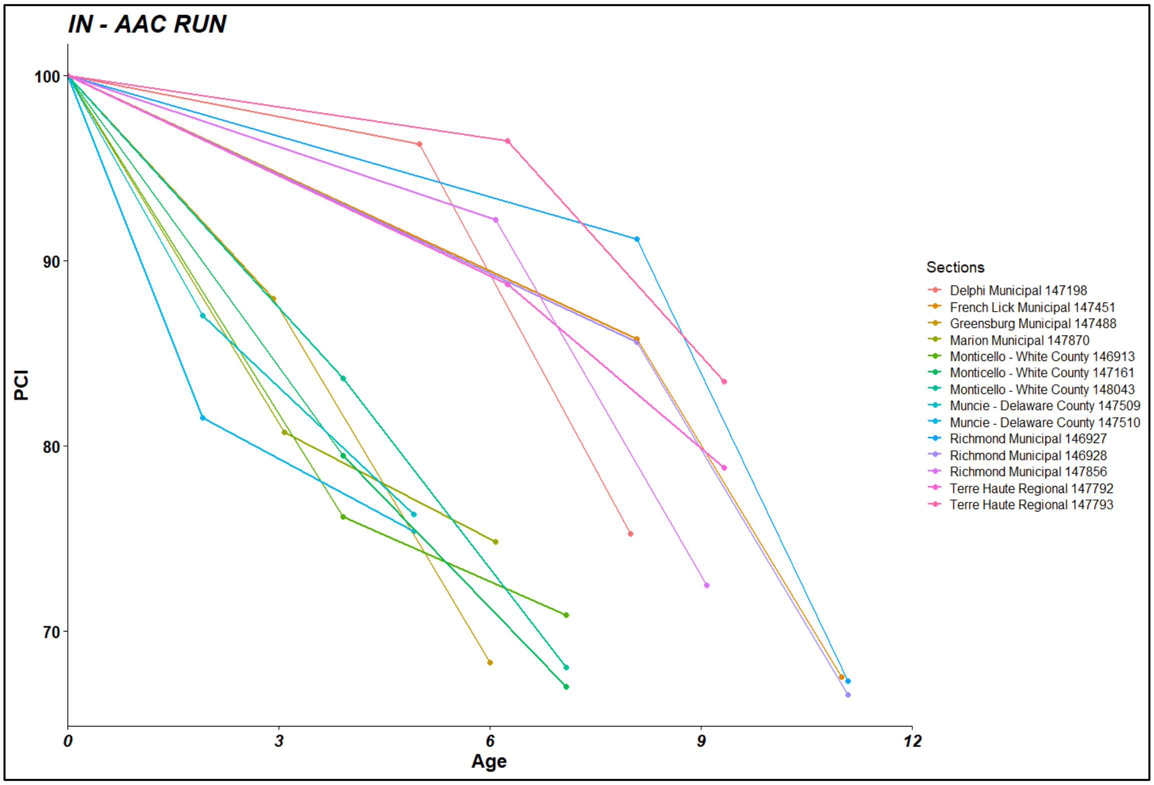


Figure 12. Identical performance trends observed for multiple sections (clusters)

4.2.2 ROD

A rate of deterioration (ROD) analysis was performed to determine the average change in a PCI per year for all pavement families. That is, the ROD refers to how much the PCI reduces per year for a given pavement family. This was achieved by fitting a simple linear regression to the PCI-Age performance for each pavement family. This effort was accomplished using Excel and JMP v 15. The datasets organized in Excel were loaded into JMP and its fit model tool was used to determine the gradient of the PCI-Age relation.

This analysis produced RODs which were used to compare the different pavement families. PAVEAIR's prediction functionality has the ability to determine the unique PCI-Age relations for the different airfield branches pavement. The ROD results obtained in this work highlighted the different performance characteristics across the different climatic regions. Additionally, the results were compared to deteriorations patterns observed for airfield pavements in the literature (Meihaus, 2013).

4.3 Regional Distress Occurrence and Visualization

The distress compositions driving the pavement performance across the different pavement families were analyzed. The DV of alligator cracking, joint reflective cracking, longitudinal cracking, raveling, rutting, and weathering were organized from the four climatic regions. The analyses ranged from a statewide frequency of occurrence, an analysis to identify the proportion of each critical distresses in the reported cases critical distress, and a dominant distress (DD) analysis. It should be noted that, there was no consideration for the pavements age in any of the distress analyses. Despite the importance of pavement age in distresses occurrence, the goal of the analyses presented was to rank the critical distresses on a basis of their impact on overall pavement performance on the different pavement families.

4.3.1 Frequency of Critical Distresses Occurrence

The first distresses analysis investigated the frequency of each critical distresses' occurrence on the pavement families, in the different climatic regions. The collected dataset was grouped into the various families and the recorded number of instances of each distress, without regards to the severity levels, was determined as the distress frequency.

4.3.2 Proportional Impact of each Critical Distress on Pavement Performance

This approach of analysis investigated the proportional impact of each individual critical distresses on the performance of the different families. For each pavement family, the proportion of a given critical distress, i, in each state was computed as the average of the DV weighted by its frequency of occurrence, as given by equation 4.3.

$$DV_i(\%) = \frac{n_i \cdot (ADV)_i}{\sum_{i=1}^{x} n_i} \times 100\% \qquad \mathbf{4.3}$$

Where $(ADV)_i$ is the average DV of critical distress i, n_i is the number of instances of critical distress i.

From this computation, the deduct component (ADV) corresponded to the relevant impact of a given critical distress on pavement performance, and the number of instances (n) corresponded to the frequency of such impact. The result from this analysis has been present in chapter 6.

4.3.3 Dominant distress (DD) analyses

The dominant distress (DD) analyses is a more granular expansion of proportional impact results. A DD was determined for each individual airfield, in the various families. The DD was defined as the critical distress with the highest average DV, at a given airfield, in a given record year. That is, for each region, three record years were selected for which the recorded DV were averaged to find the distress that reported the highest average. The results from these analyses are summarized and presented in Chapter 6, and graphical representation of the results are also presented in Appendix C.

CHAPTER 5. STATEWIDE PAVEMENT CONDITION ANALYSES RESULTS AND INTEPRETATIONS

The typical PCI-Age performance observed revealed that certain sections, or clusters, within a family show very identical performance but that performance cannot be generalized for the entire family due to occurrence of multiple clusters within the same pavement family. The observed trends also revealed that sections at the same airports usually belonged to the same clusters in the family. This observation alludes that performance is typically dictated on a granular level by local pavement operation conditions and that broader family assignments might not necessarily give good insight into performance. As such, ROD analyses for both pavement families, and clusters within the families were performed, and the results have been presented in the sections below.

5.1 ROD Results for Pavement Families

The ROD for a given family was defined as the average annual reduction in PCI value for such pavement family. Thus, it was taken as the slope of the linear regression line fitted to the PCI-Age performance. The results for AAC, and AC pavement families are presented in Table 3 and Table 4 respectively.

Table 3. ROD of Various AAC Pavement Families

	APRONS				**RUNWAYS**				**TAXIWAYS**			
	WF	**DF**	**DNF**	**WNF**	**WF**	**DF**	**DNF**	**WNF**	**WF**	**DF**	**DNF**	**WNF**
No.[1] Sections	18	1	16	7	25	12	28	21	77	3	29	21
ROD	3.5	2.4	4.0	2.8	2.8	2.4	2.8	2.4	3.5	0.5	2.8	2.3
RMSE[2]	8.3	1.7	14.4	4.6	6.1	4.6	13.0	6.1	10.6	7.3	11.6	5.9

[1] No.: Number, [2] Root Mean Square of Error

Table 4. ROD of Various AC Pavement Families

	APRONS				RUNWAYS				TAXIWAYS			
	WF	**DF**	**DNF**	**WNF**	**WF**	**DF**	**DNF**	**WNF**	**WF**	**DF**	**DNF**	**WNF**
No. Sections	25	9	44	11	12	14	24	8	97	18	55	23
ROD	2.9	1.4	2.8	1.7	2.3	2.0	2.5	1.9	2.5	1.8	2.7	2.3
RMSE	7.2	8.6	11.7	7.6	6.0	7.1	10.1	6.9	7.2	8.0	9.3	5.6

The results revealed that the average ROD ranges from 2.4 to 4.0 points of PCI deduct per year for AAC pavements and 1.4 to 2.8 for AC pavements. For AAC pavements, while aprons generally showed relatively poor performance with the two highest RODs (3.5 and 4.0), runways show a slower and more consistent ROD ranging between 2.4 and 2.8 points of PCI deduct per year. Similar observations were made for AC pavements with aprons reporting the highest ROD (2.8 and 2.9) and runways showing the narrowest ROD range (1.9 to 2.5).

These results, especially those obtained for runways, were consistent with expectations and literature (Meihaus, 2013). Runways are expected to have higher priority in maintenance and rehabilitation programs and may be designed especially due to their expected high functionality level, which may result in better and more improved performance across the climatic regions. Also, the typical slow-rolling aircraft movement on aprons could be causing its faster deterioration.

5.2 ROD for Clusters within Pavement Families

The ROD for the clustered sections, identified as fast, moderate, and slow deteriorating, were similarly determined from the slope of the linear regression line fitted to the clustered PCI-Age performance. Figure 13 below depicts the non-clustered family performance and the cluster performance.

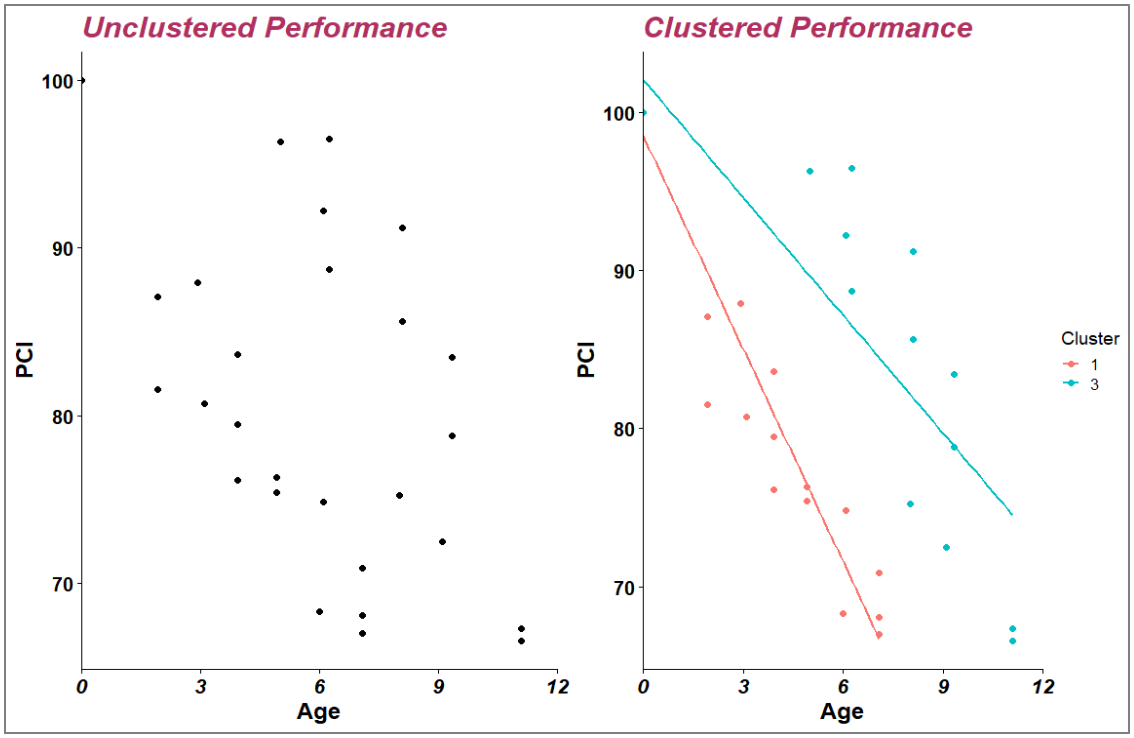


Figure 13. Non-clustered and clustered performance fitted with Linear regression line

The result from this analysis have been presented in Table 5 and Table 6 below. As mentioned in Chapter 6, the clusters were visually assigned based on observable identical performance for a number of pavement sections and thus, a given family could be retained non-clustered, or clustered into on or two clusters.

Table 5. ROD results for Different AAC Family Clusters

Branch	Cluster	WF	WNF	DF	DNF
Apron	**Fast**	5.0	3.7	2.7	5.9
	Moderate	-	-	-	3.9
	Slow	2.9	2.6	2.3	2.3
Runways	**Fast**	4.8	3.8	-	4.8
	Moderate	3.0	2.5	-	3.2
	Slow	2.4	1.0	-	1.4
Taxiways	**Fast**	7.0	3.7	-	4.0
	Moderate	4.1	-	-	-
	Slow	1.9	2.1	-	2.4

Table 6. ROD results for Different AC Family Clusters

Branch	Cluster	WF	WNF	DF	DNF
Apron	**Rapid**	3.8	2.6	3.7	5.0
	Medium	-	-	-	2.9
	Slow	2.4	0.8	1.3	1.8
Runways	**Rapid**	4.1	4.3	3.1	3.7
	Medium	2.7	-	-	-
	Slow	1.5	1.6	1.7	1.6
Taxiways	**Rapid**	4.3	3.3	3.4	3.7
	Medium	2.8	-	-	-
	Slow	1.5	1.7	1.8	2.1

The ROD ranges from this analysis were 1.0 to 7.0 0 PCI reduction per year and 0.8 to 5.0 PCI reduction per year for AAC and AC pavements respectively. This alludes to more variable section performance within the same pavement families.

5.3 ROD Correlation with Freezing Index

The clustered analysis results were additionally used to investigate the role of temperature in the performance deterioration. As an illustration, the FI of DNF region airfields with multiple sections, in at least one AAC pavement family, was studied against the ROD for the cluster in which sections from that airfield belong as summarized in Table 7

Table 7. Correlating Cluster ROD with FI

Airfield	Rate of Deterioration (ROD)			FI
	Apron	Runway	Taxiway	
Artesia Municipal Airport	-	3.2	4.0	29.6
Cavern City Air Terminal (Carlsbad)	2.3	3.2	2.4	23.2
Deming Municipal Airport	-	4.8	2.4	3.6
Gallup Municipal Airport	-	3.2	2.4	324.3
Las Vegas Municipal Airport	2.3	1.4	2.4	245.9
Lea County Regional Airport (Hobbs)	5.9	3.2	2.4	37.0
Moriarty Airport	-	4.8	2.4	174.5
Raton Municipal Airport/Crews Field	-	4.8	4.0	338.5
Santa Fe Municipal Airport	-	21.8	7.5	194.4

The high FI values at some of the airports showed that the airfields in DNF region can be subjected to the climatic conditions similar to those observed in WF regions. Also, there was no clear correlation observed between FI and pavement performance. Airfields with similar climates, expressed by FI, did not seem to have similar performances. For instance, Artesia Municipal Airport and Cavern City Air Terminal (Carlsbad) have identical FI and their runway sections fall under the same cluster, but that is not the case for their taxiway sections. Additionally, although Gallup Municipal Airport and Raton Municipal Airport/Crews Fields have identical FI, they do not show similar deterioration for any pavement family. It can be concluded that the differences in performance between the clusters are not sufficiently explicable by climate data alone.

CHAPTER 6. STATEWIDE DISTRESS ANALYSES RESULTS AND INTEPRETATIONS

6.1 Frequency of Critical Distresses Occurrence

The frequencies of the instances of each critical distress for pavement families in the WF, DNF, DF, and WNF regions have been presented in Table 8, Table 9, Table 10, and Table 11 respectively.

Table 8. Distresses Frequencies for all Pavement Families in WF region

Surface	BranchUse	ALLIGATOR CR[1]	L & T CR[2]	RAVELING	RUTTING	WEATHERING
AAC	APRON	29	209	58	1	122
AAC	RUNWAY	21	721	103	9	445
AAC	TAXIWAY	126	803	194	33	598
AC	APRON	67	362	76	18	210
AC	RUNWAY	14	488	55	21	339
AC	TAXIWAY	142	1213	152	46	917
Total		**399**	**3796**	**638**	**128**	**2631**

[1] ALLIGATOR CR: Alligator cracking, [2] L & T CR: Longitudinal and transverse cracking

Table 9. Distresses Frequencies for all Pavement Families in DNF region

Surface	BranchUse	ALLIGATOR CR	L & T CR	RAVELING	RUTTING	WEATHERING
AAC	**APRON**	51	3	71	4	191
AAC	**RUNWAY**	73	7	266	1	249
AAC	**TAXIWAY**	74	5	184	18	381
AC	**APRON**	225	19	363	20	749
AC	**RUNWAY**	89	13	120	15	312
AC	**TAXIWAY**	205	19	209	51	766
Total		**717**	**66**	**1213**	**109**	**2648**

Table 10. Distresses Frequencies for all Pavement Families in DF region

Surface	BranchUse	ALLIGATOR CR	L & T CR	RAVELING	RUTTING	WEATHERING
AAC	APRON	2	64	4	-	14
AAC	RUNWAY	54	372	22	-	26
AAC	TAXIWAY	11	175	34	1	8
AC	APRON	2	87	14	-	15
AC	RUNWAY	35	731	48	8	52
AC	TAXIWAY	72	459	31	13	55
Total		**176**	**1888**	**153**	**22**	**170**

Table 11. Distresses Frequencies for all Pavement Families in WNF region

Surface	BranchUse	ALLIGATOR CR	JT REF. CR[1]	L & T CR	RAVELING	RUTTING	WEATHERING
AAC	APRON	12	-	528	85	13	62
AAC	RUNWAY	26	2	1424	259	19	242
AAC	TAXIWAY	29	-	892	191	4	96
AC	APRON	52	-	874	214	12	195
AC	RUNWAY	4	-	344	87	1	67
AC	TAXIWAY	75	-	1191	311	50	183
Total		**198**	**2**	**5253**	**1147**	**99**	**845**

[1] JT REF. CR: Joint Reflective cracking

6.2 Proportional Impact of Each Critical Distress

This section presents the critical distresses proportional impact analysis results. The analyses investigated the impact of each critical distress on the various pavement families. The results are presented in Figure 14 - Figure 19.

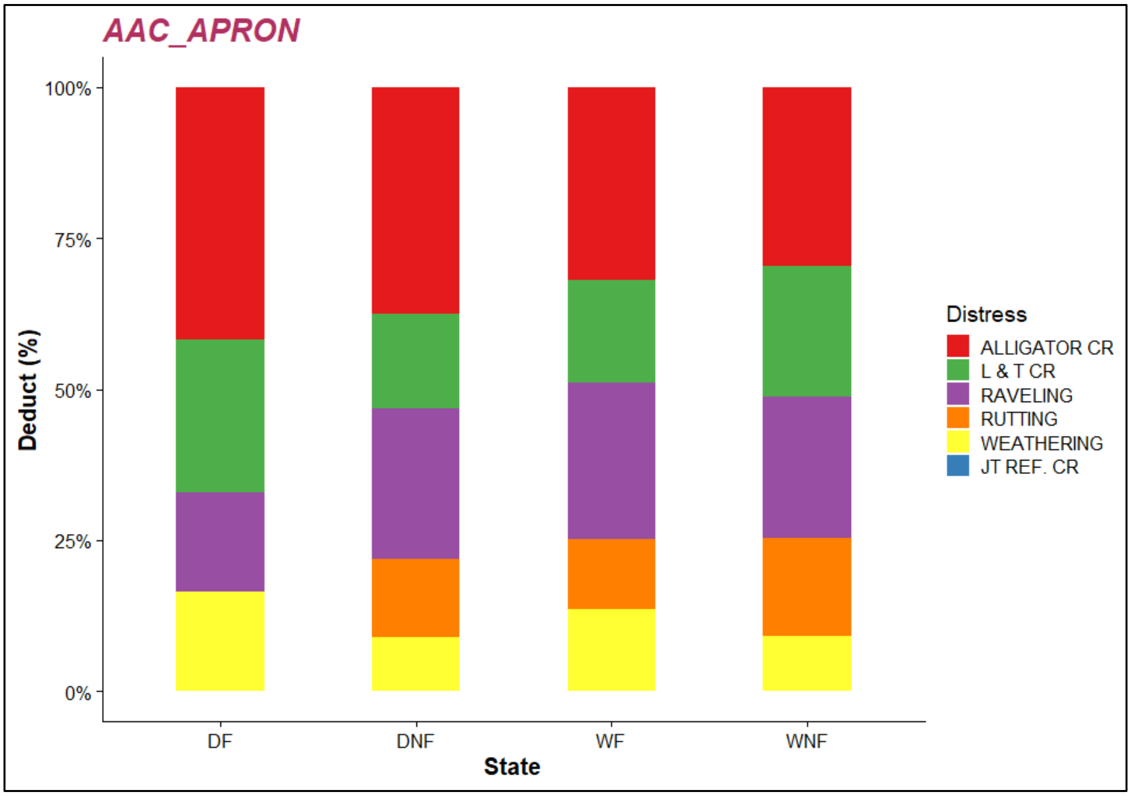


Figure 14. Proportional Impact of Critical Distresses on AAC Apron Pavements

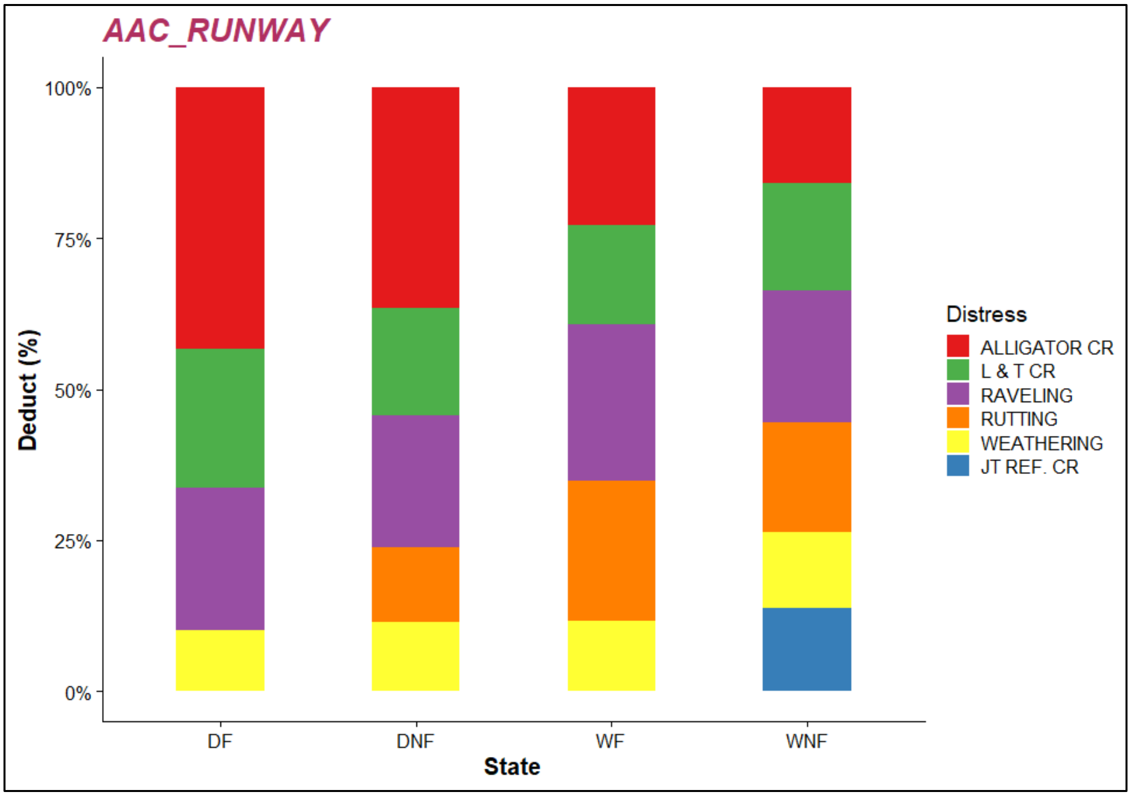


Figure 15. Proportional Impact of Critical Distresses on AAC Runway Pavements

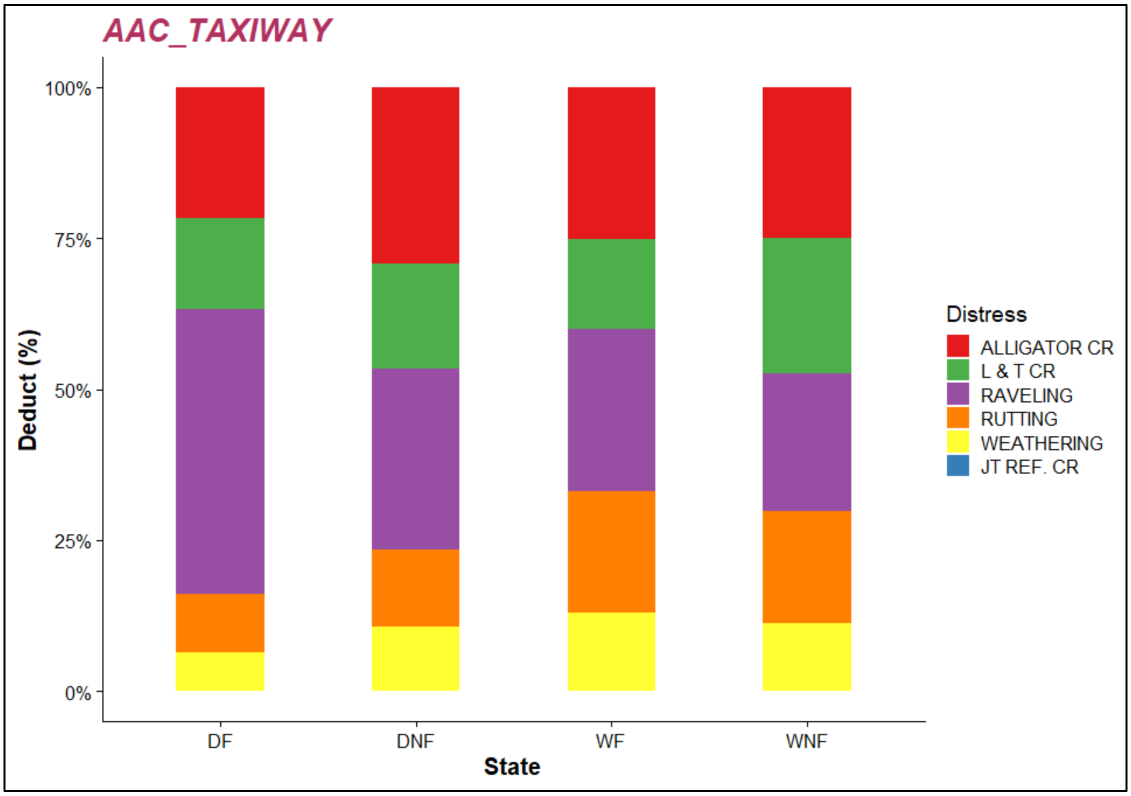


Figure 16. Proportional Impact of Critical Distresses on AAC Taxiway Pavements

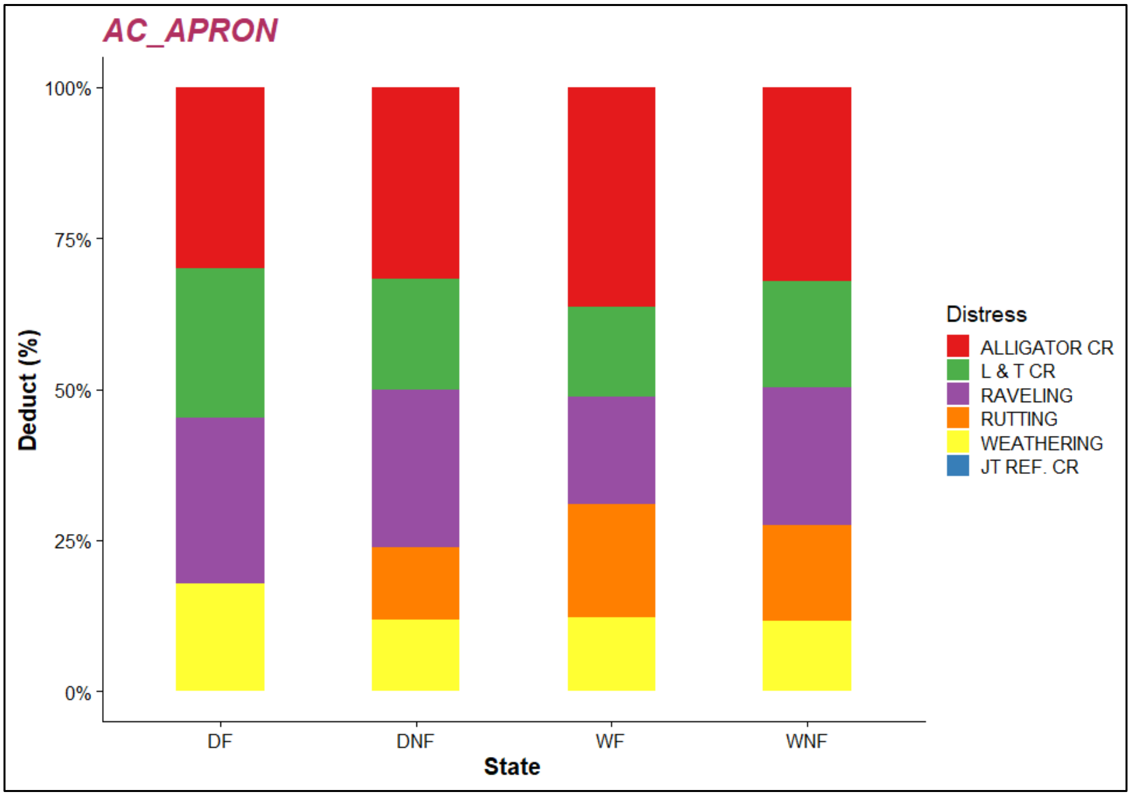


Figure 17. Proportional Impact of Critical Distresses on AC Apron Pavements

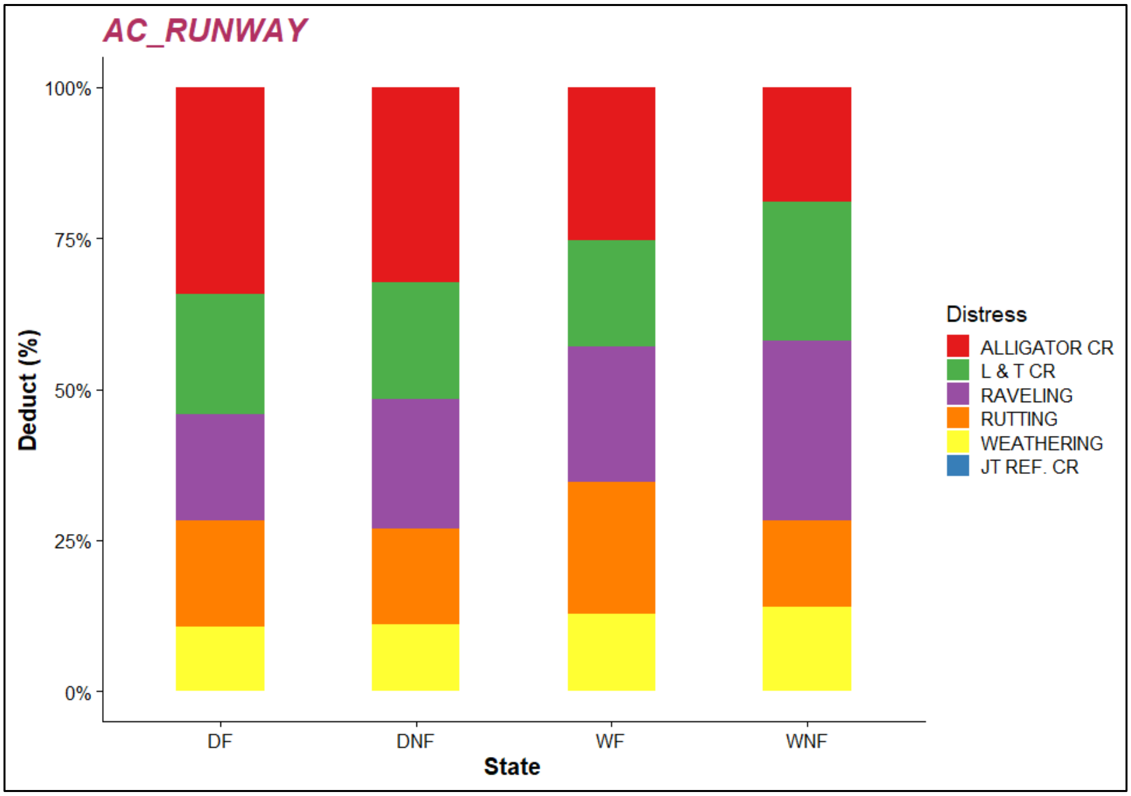


Figure 18. Proportional Impact of Critical Distresses on AC Runway Pavements

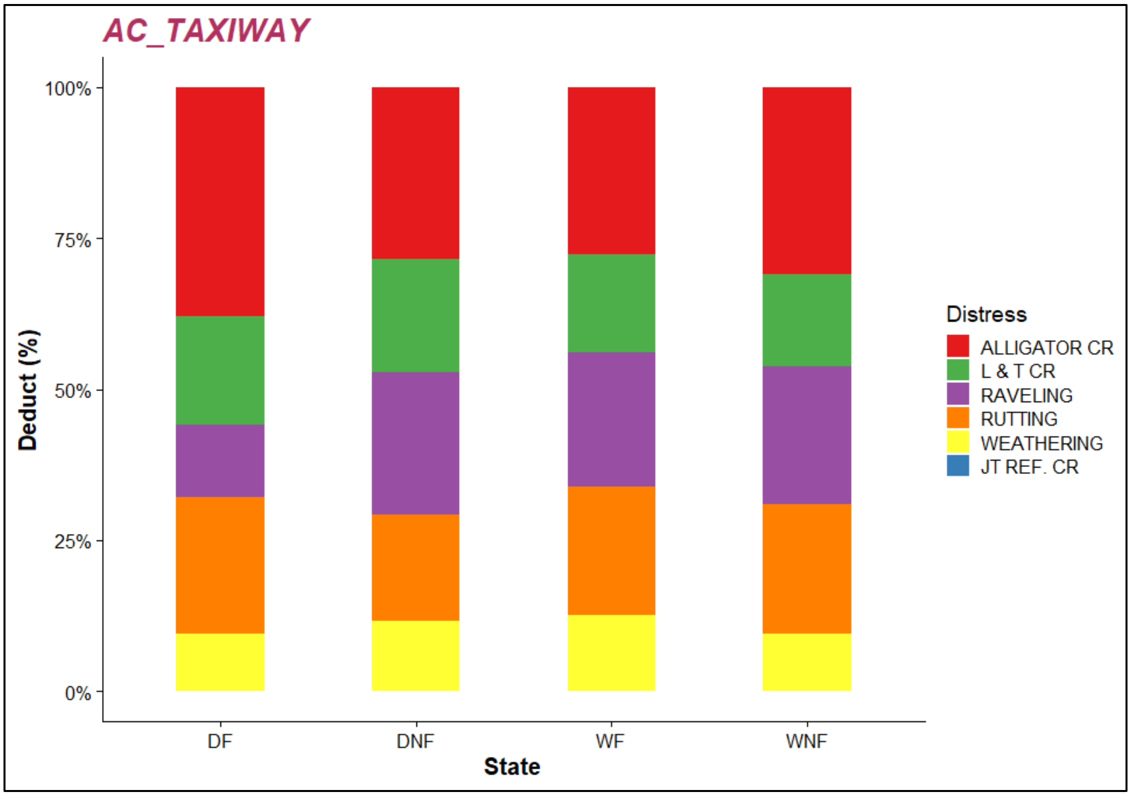


Figure 19. Proportional Impact of Critical Distresses on AC Taxiway Pavements

The impact of distresses on the overall pavement condition appeared to be similar for AC and AAC pavements. Despite a lower occurrence rate as shown in Table 8 through Table 11, alligator cracking constituted the highest percentage of the total DV (approximately 25 to 45%). The percentage contribution of alligator cracking appeared to be more apparent for New Mexico and Nevada airfields. Raveling and longitudinal and transverse cracking distresses have the second and third highest contribution, respectively, to the total DV, followed by rutting and weathering. Raveling had the highest impact on the airfields in Nevada in particular with approximately a 50% contribution to total DV. It is also important to note that overall performance of pavement sections was not significantly affected by rutting distress, which is known as a major safety issue and pavement structural problem for airfield facilities and highway pavements. However, regardless of the pavement family type, the order of significance of distresses remained consistent. This indicates that, pavement deterioration cannot singlehandedly be explained by the FI.

6.3 Dominant Distress

The DD analysis identified the distress that impacted performance the most at the various airports. The number of airports reporting a given distress as dominant in each climatic region provides insight into the prevalence of that distress in the given region. Table 12 and Table 13 summarizes the results for the DD analyses with the number of airfields reporting a dominant distress in each state for both AAC and AC pavements. The results from the different locations were used to infer characteristics peculiar to those regions.

Table 12. Number of Airfields in each Critical distress as Dominant on AAC Pavement Families

Distress	APRON				RUNWAY				TAXIWAY			
	WF	DNF	DF	WNF	WF	DNF	DF	WNF	WF	DNF	DF	WNF
ALLIGATOR	7	6	1	8	4	7	1	1	15	6	2	8
L & T CR	11	1	2	27	16	1	5	42	13	1	4	26
RAVELING	5	4	-	5	3	10	2	8	8	8	1	9
RUTTING	1	-	-	2	1	-	-	3	1	1	-	1
WEATHERING	4	4	-	1	9	8	-	1	15	5	1	3

Table 13. Number of Airfields in each Critical distress as Dominant on AC Pavement Families

Distress	APRON				RUNWAY				TAXIWAY			
	WF	DNF	DF	WNF	WF	DNF	DF	WNF	WF	DNF	DF	WNF
ALLIGATOR	12	20	1	13	3	9	5	-	15	18	10	10
L & T CR[1]	14	5	3	22	16	2	10	14	22	3	7	20
RAVELING	4	7	1	7	3	8	3	3	5	8	-	14
RUTTING	-	2	-	-	1	-	-	-	1	2	-	2
WEATHERING	8	5	1	4	8	6	1	2	9	7	-	2

For the recorded years of the study, at least 60% of airfield AAC pavements recorded either alligator cracks, longitudinal and transverse cracks, or both as the distress(es) most detrimental to pavement performance. Exceptions were observed for families in the DNF region where about 60% of airfields reported either raveling or weathering as the dominant distress. It is noteworthy that longitudinal and transverse crack dominance was more pronounced in the WNF region where an average 65% of airfields recorded this distress as dominant. Rutting was reported as the dominant distress in less than 5% of airfields in the WF and WNF regions with one instance for taxiways in the DNF region. There were no remarkable differences in the trend of load-related distresses across the branches.

Boudreau et al. indicated temperature as a key contributor to transverse cracks and construction quality as the main contributor to longitudinal cracks (Boudreau, Christopher, & Schwartz, 2006). The high cracking dominance in the WF region can be attributed to cold weather and high precipitation. High precipitation, and thus the presence of moisture, was also identified to accelerate the crack propagation. In the DF region, the climate data revealed extensive daily temperature variations and high FIs.

These combined conditions contributed to the frequency of freeze-thaw cycles and accelerated asphalt pavement cracking. On the other hand, the WNF region showed more consistent average temperatures within any given month and less severe winters. The reason for the reported high longitudinal and transverse cracks is unclear from the climatic standpoint. Therefore, construction quality, material selection, and design practices should be investigated to determine the root causes for pavement cracking in these airfields.

The dominant distress trends on the AC pavements were very similar to those of the AAC pavements. The noticeable difference was the increase in the number of airfields reporting alligator cracks as dominant, from an average of 32% to 45%. This could have resulted from the difference in structural design for the two pavement types. However, the structural characteristics were not covered in this study.

6.4 Deduct Value Correlation with Freezing Index

This section presents the results of the attempt to determine significance of freezing index to the average DV of the individual distresses. For each critical distress, the average DV for all airfields in a family was determined to be regressed against the airfields' location FI. Figure 20 and Figure 21 present the results for Longitudinal and Transverse cracks for AAC and AC pavement families respectively. The remainder of the result are available in Appendix D.

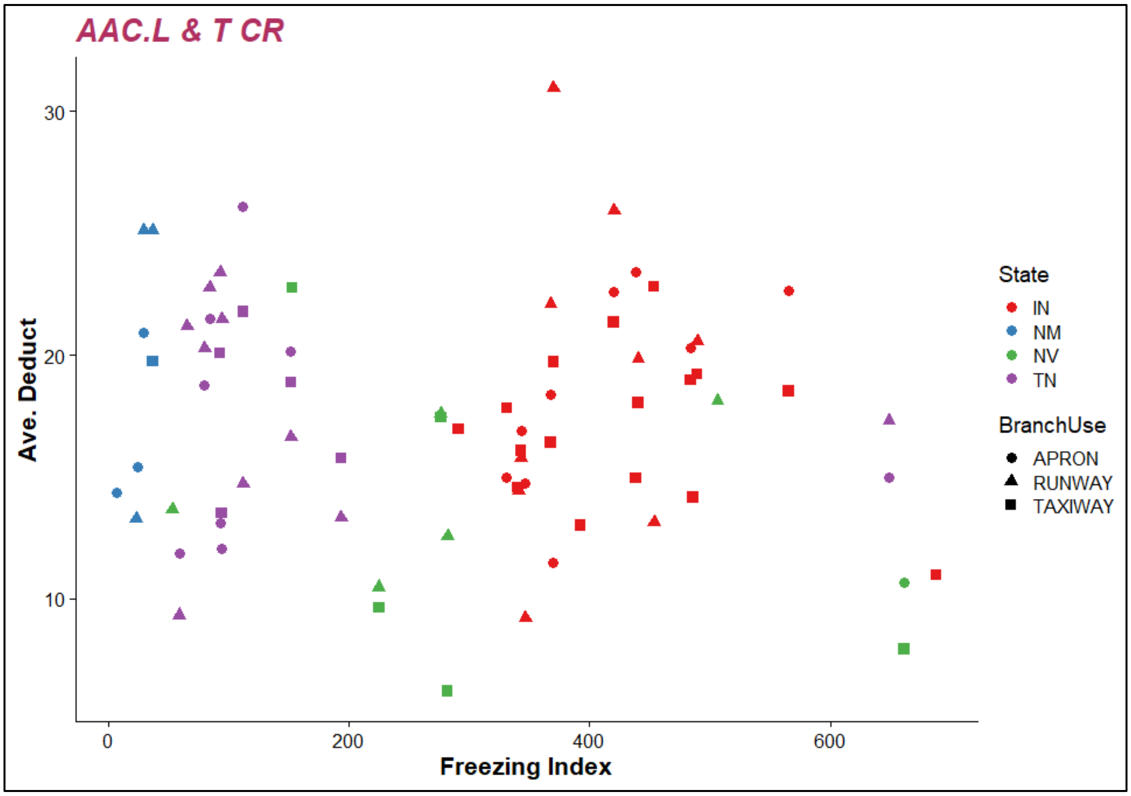


Figure 20. Longitudinal and Transverse cracking DV Correlation with FI for AAC Pavement Families

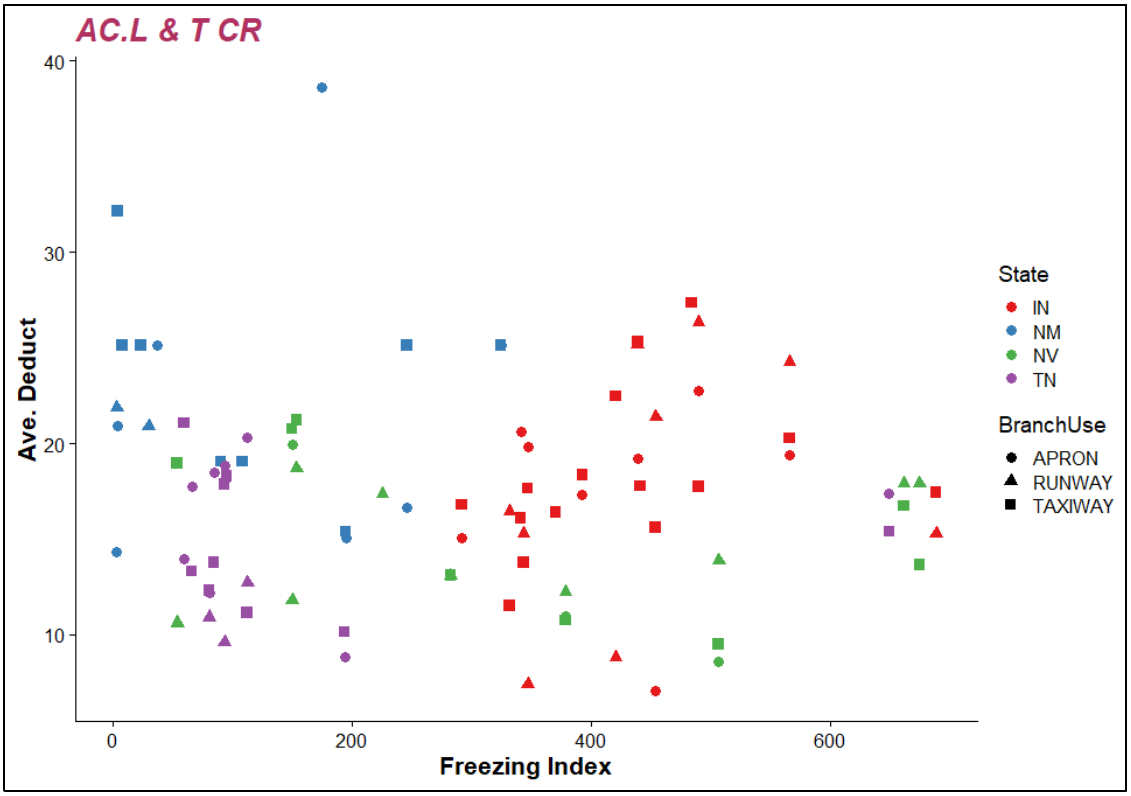


Figure 21. Longitudinal and Transverse cracking DV Correlation with FI for AC pavement families

The results did not reveal any significant correlation between the resulting average DV and the location's FI.

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions From Research Effort

The goal of this study was to evaluate pavement deterioration trends in the airfield facilities of different climatic regions. FAA’s PAVEAIR repository was used to collect historical pavement condition and distress data, which were organized into family datasets. Climate data were also retrieved from the NCEI-NOAA online database to correlate climate contribution in performance and distresses trends. Pavement conditions were analyzed to evaluate PCI progression in aprons, taxiways, and runways using clustering analysis. Distress analyses were performed to determine most critical distresses affecting pavement performance and evaluate any trends between pavement facilities in different climatic regions. Below are the main findings and observations:

- Clustering analysis was shown to be effective in grouping pavement facilities with distinctive pavement deterioration trends identified as slow, moderate, and fast. The result revealed that 75% of sections belonging to the same family at a particular airfield showed similar deterioration trends.
- In some cases, clusters consisted of sections from airfields in one state that had very different climatic conditions (e.g., FI and minimum and maximum temperatures in New Mexico and Nevada). Therefore, climatic parameters were not found to correlate very well with the performance outcome. In order to understand pavement performance in a large and heterogenous dataset such as the dataset used in this study, traffic, structural, and construction quality parameters need to be included.

- The ROD parameter was developed to summarize pavement deterioration patterns quantitatively. The ROD parameter was derived from linear regression of the PCI to pavement age data with an acceptable correlation coefficient. According to the data, the average ROD ranged from 2.4 to 4.0 points of PCI deduct per year.
- Runways had the lowest ROD in all regions except in the DF region where there was not a large enough number of sections to make a conclusion. Aprons had the highest ROD in all regions, which could be due to the nature of slow-moving aircraft.
- In terms of climatic regions, the families in the WF region had the highest ROD, followed by the pavements in the DNF region. The fact that the pavements in the DNF region were deteriorating as fast as regions identified as WF regions can be attributed to geographic variability in New Mexico. This resulted in greater climatic variability, hence the pavement performance deterioration.
- According to the distress analyses, longitudinal and transverse cracking and alligator cracking were most occurring distresses in all of the regions regardless of the pavement facility and type. They had the highest contribution to the overall distress DVs. Raveling and weathering followed these two. Rutting was found to be the least contributing distress to the overall pavement condition indicating the proper selection of materials and satisfactory structural designs to carry the intended loads.

7.2 Recommendations for Future Research and Practical Considerations

- Performance of AAC and AC pavements were found to be very similar. In future data analyses, these two pavement types should be grouped together to populate the database.
- The reporting of longitudinal and transverse cracking can be separated into wheelpath longitudinal, non-wheelpath longitudinal, and transverse cracking. This will allow identifying root causes of the problem (i.e., whether it is a structural, load-related, environmental, or construction quality problem).
- Due to heterogenous characteristics of the airfield pavement facilities and stark differences in the way these pavements are subjected to aircraft movements, an accurate prediction of future pavement performance needs additional variables. There is at least a need to combine or append the FAA's PAVEAIR repositories with traffic and basic structural information.

Airports from additional states in similar climatic regions should be used to expand the research to include more data point

REFERENCES

AASHTO (1993). AASHTO guide for design of pavement structures 1993, AASHTO, Washington, D.C.

Al-Qadi, I. L., Hassan, M. M., & Elseifi, M. A. (2005). Field and theoretical evaluation of thermal fatigue cracking in flexible pavements. Transportation research record, 1919(1), 87-95

ASTM D5340-12 (2018) Standard Test Method for Airport Pavment Condition Index Surverys, ASTM International, West Conshohocken, PA

Barua, L., Zou, B., Noruzoliaee, M., & Derrible, S. (2020). A gradient boosting approach to understanding airport runway and taxiway pavement deterioration. International Journal of Pavement Engineering, 1-15.

Boudreau, R., Christopher, B. R., & Schwartz, C. (2006). Geotechnical Aspects of Pavements. (Technical No. FHWA NHI-05-037). Washington DC: US Department of Transportation Federal Highway Administration.

Buchanan, S. (2017). Balanced Mix Design (BMD). In Annual conference of the Association of Asphalt Paving Technologies, CA, USA..

FAA. (1997). AC 150/5380-9. Measurement, Construction, and Maintenance of Skid Resistant Airport Pavement Surfaces

FAA. (2009). AC 150/5320-12C. Guidelines and Procedures for Measuring Airfield Pavement Roughness.

FAA. (2014). AC 150/5320-17A. Airfield Pavement Surface Evaluation and Rating Manuals.

FAA. (2014). AC 150/5335-5C. Standardized Method of Reporting Airport Pavement Strength - PCN

FAA. (2014). AC 150/5380-7B. Airport Pavement Management Program (PMP)

FAA. (2016). AC 150/5320–6F. Airport Pavement Design and Evaluations.

FAA. (2020). National Plan of Integrated Airport Systems (NPIAS) 2021–2025.

FAA. (2021). Airport Improvement Program (AIP). Retrieved from Federal Aviation Administration: https://www.faa.gov/airports/aip/

Haas, R. (2001). Reinventing the (Pavement Management) Wheel. Distinguished Lecture at Fifth International Conference on Managing Pavements, Seattle, Washington.

Hajek, J. J. (2011). Common airport pavement maintenance practices (Vol. 22). Transportation Research Board.

Li, Q., Mills, L., & McNeil, S. (2011). The Implications of Climate Change on Pavement Performance and Design. University of Delaware University Transportation Center.

Li, Q., Xiao, D. X., Wang, K. C., Hall, K. D., & Qiu, Y. (2011). Mechanistic-empirical pavement design guide (MEPDG): a bird's-eye view. Journal of Modern Transportation, 19(2), 114-133.

Llopis-Castelló, D., García-Segura, T., Montalbán-Domingo, L., Sanz-Benlloch, A., & Pellicer, E. (2020). Influence of pavement structure, traffic, and weather on urban flexible pavement deterioration. Sustainability, 12(22), 9717.

Meihaus, J. C. (2013). Understanding the Effects of Climate on Airfield Pavement Deterioration Rates. Air Force Institute of Technology Wright-Patterson AFB OH Graduate School of Engineering And Management.

Peng, X., Zhang, T., Cao, B., Wang, Q., Wang, K., Shao, W., & Guo, H. (2016). Changes in freezing-thawing index and soil freeze depth over the Heihe River Basin, western China. Arctic, Antarctic, and Alpine Research, 48(1), 161-176.

Sahagun, L. (2014). Modeling Pavement Distress Rates within US Air Force Airfields.

Shahin, M.Y. (2005). Pavement Management for Airports, Roads, and Parking Lots (2nd Edition). New York: Springer.

Shahin, M.Y. (1994). Pavement Management for Airports, Roads, and Parking Lots. New York: Springer.

Sotil, A., & Kaloush, K. (2004). "Development of Pavement Performance Models for DelhiTownship, Ohio Pavement management System." Compendium of Papers CD-ROM, 73. Meeting of the Transportation Research Board, National Research Council, Washington, D. C.

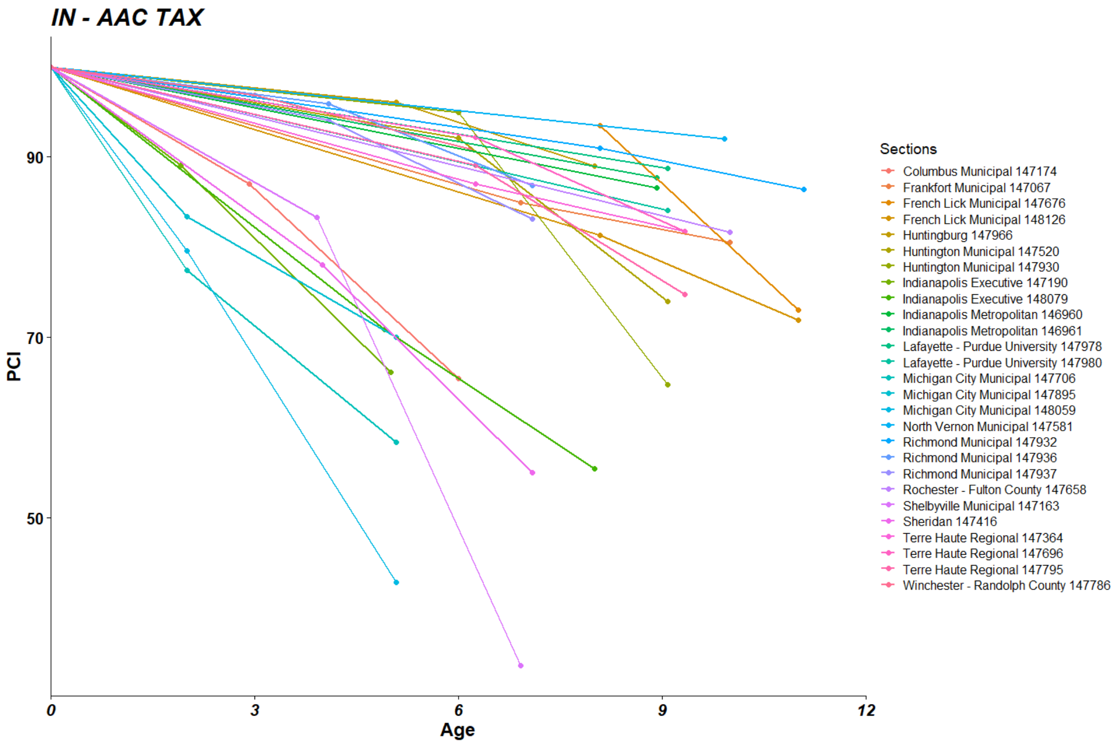
Tighe, S. L., Cowe Falls, L., Haas, R., & MacLeod, D. (2006). Climate impacts and adaptations on roads in Northern Canada (No. 06-1380).

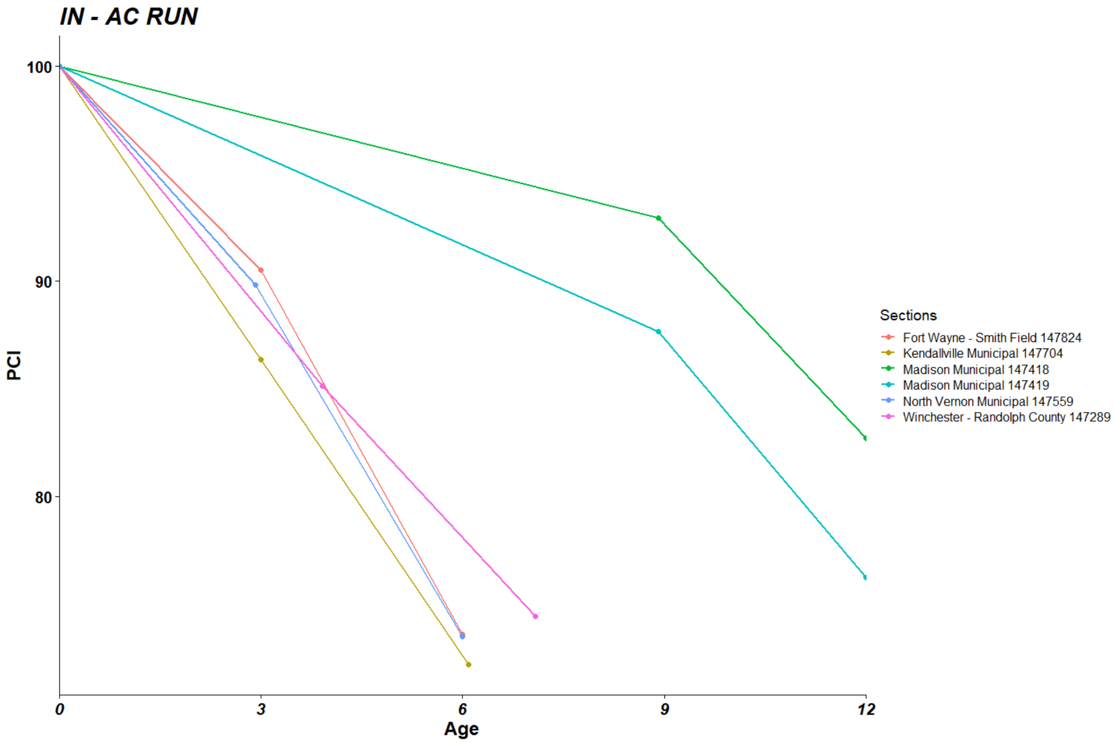
Ullidtz, P., Harvey, J., Basheer, I., Jones, D., Wu, R., Lea, J., & Lu, Q. (2010). CalME, a Mechanistic–Empirical Program to Analyze and Design Flexible Pavement Rehabilitation. Transportation Research Record, 2153(1), 143-152.

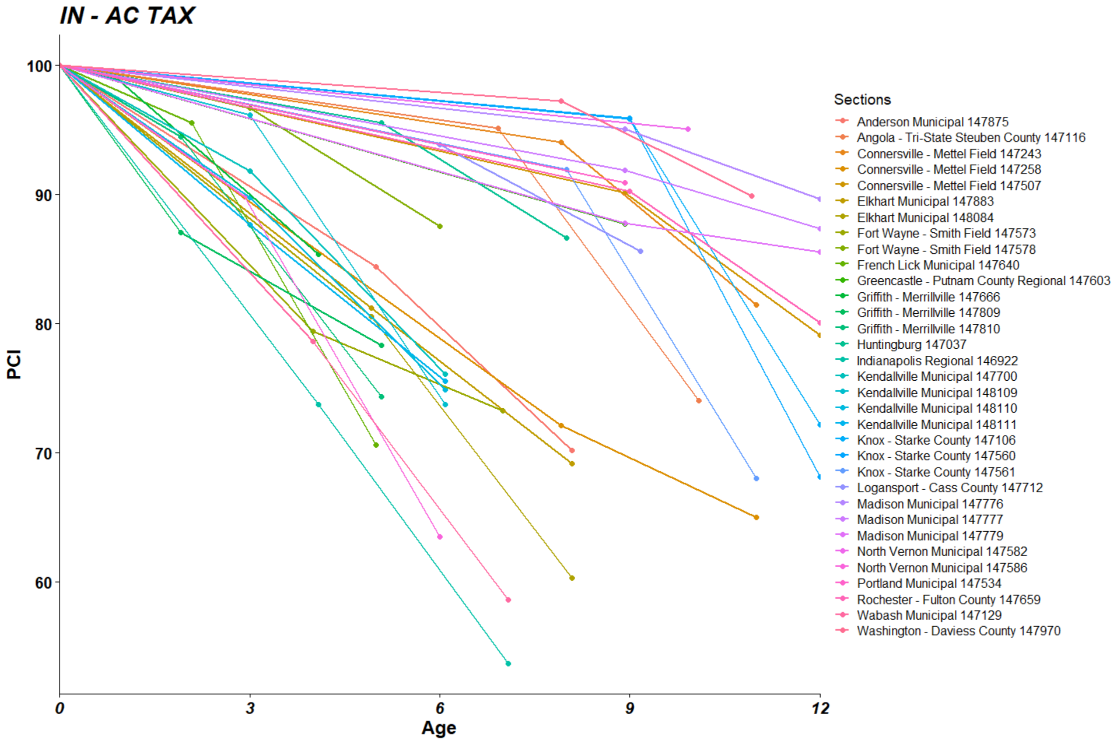
Wu, R. (2005). Finite element analyses of reflective cracking in asphalt concrete overlays. University of California, Berkeley

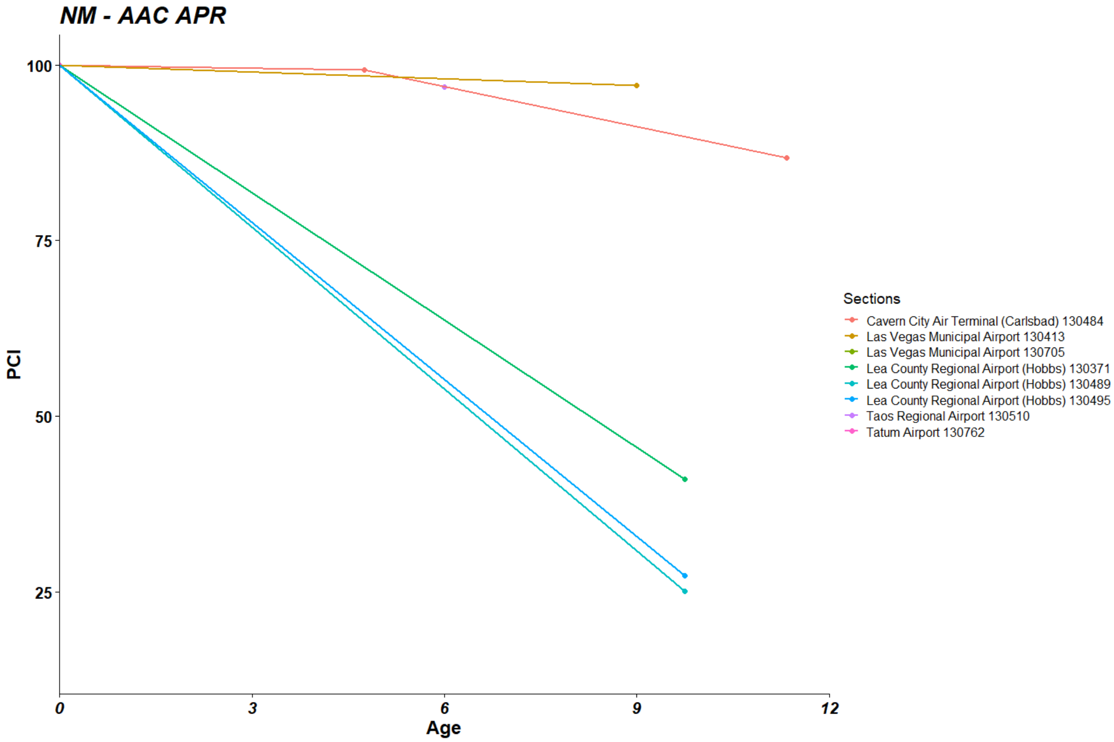
APPENDIX A

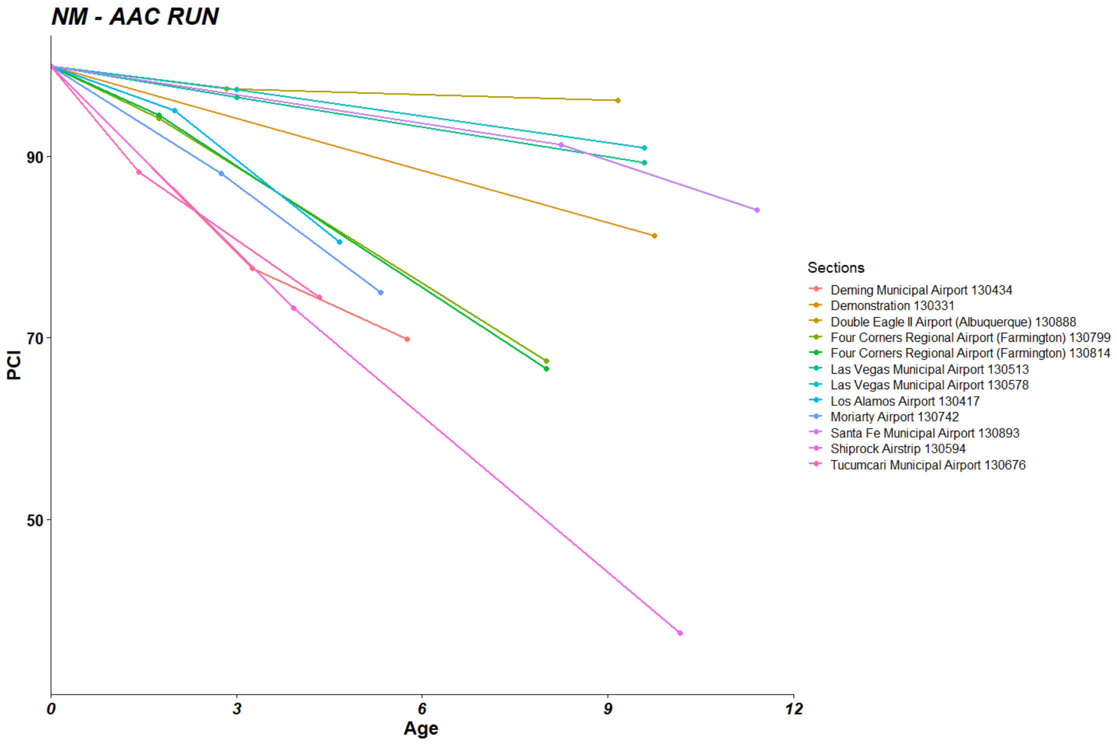
PAVEMENT CLUSTER RESULTS FOR ALL AIRFIELD PAVEMENT FAMILIES

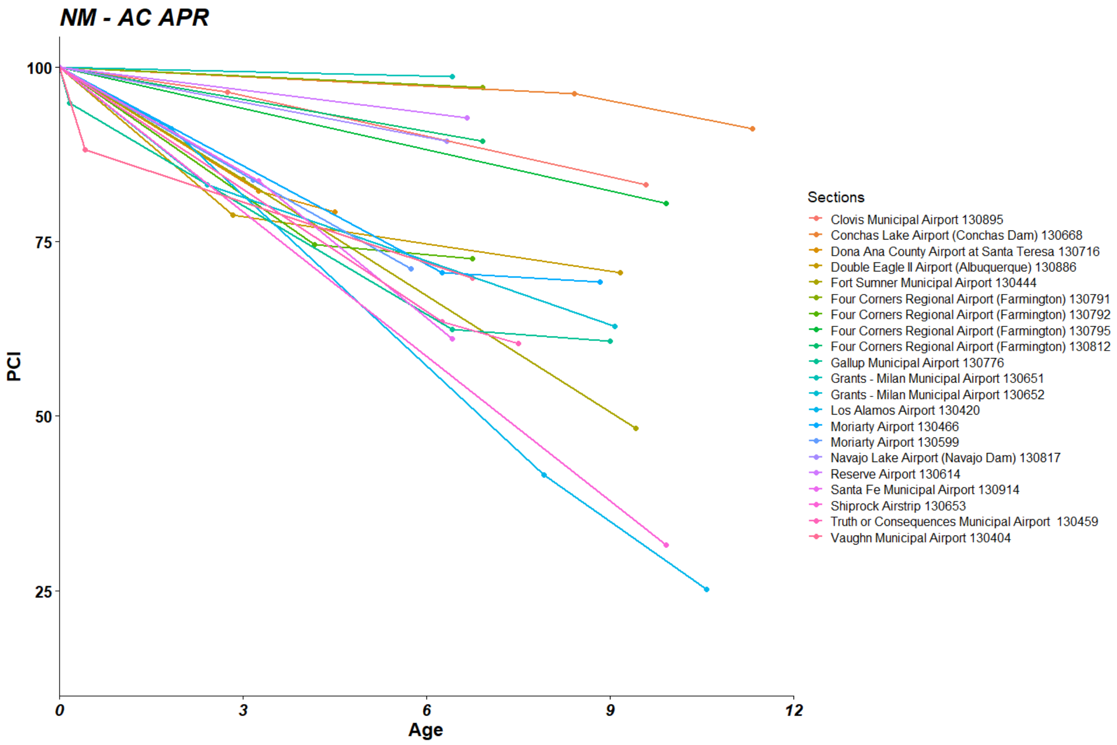

IN - AAC TAX
PCI
90
70
50
Age
0
3
6
9
12
Sections
Columbus Municipal 147174
Frankfort Municipal 147067
French Lick Municipal 147676
French Lick Municipal 148126
Huntingburg 147966
Huntington Municipal 147520
Huntington Municipal 147930
Indianapolis Executive 147190
Indianapolis Executive 148079
Indianapolis Metropolitan 146960
Indianapolis Metropolitan 146961
Lafayette - Purdue University 147978
Lafayette - Purdue University 147980
Michigan City Municipal 147706
Michigan City Municipal 147895
Michigan City Municipal 148059
North Vernon Municipal 147581
Richmond Municipal 147932
Richmond Municipal 147936
Richmond Municipal 147937
Rochester - Fulton County 147658
Shelbyville Municipal 147163
Sheridan 147416
Terre Haute Regional 147364
Terre Haute Regional 147696
Terre Haute Regional 147795
Winchester - Randolph County 147786

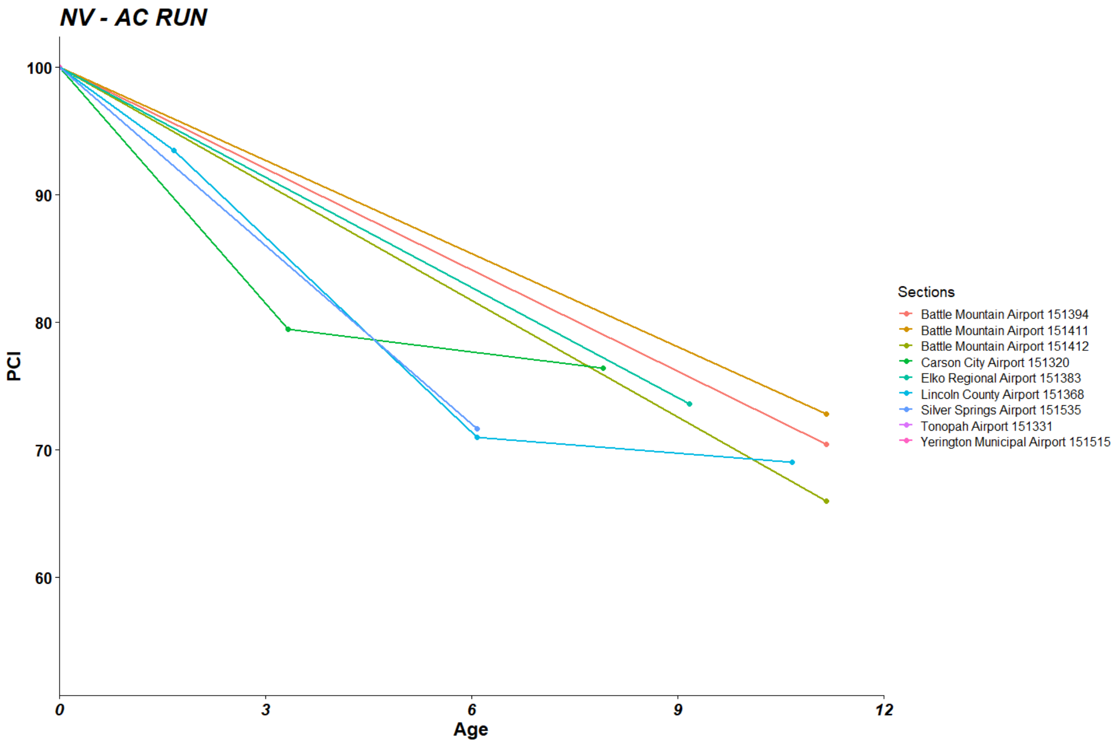

IN - AC RUN
PCI
100
90
80
Age
0
3
6
9
12
Sections
Fort Wayne - Smith Field 147824
Kendallville Municipal 147704
Madison Municipal 147418
Madison Municipal 147419
North Vernon Municipal 147559
Winchester - Randolph County 147289

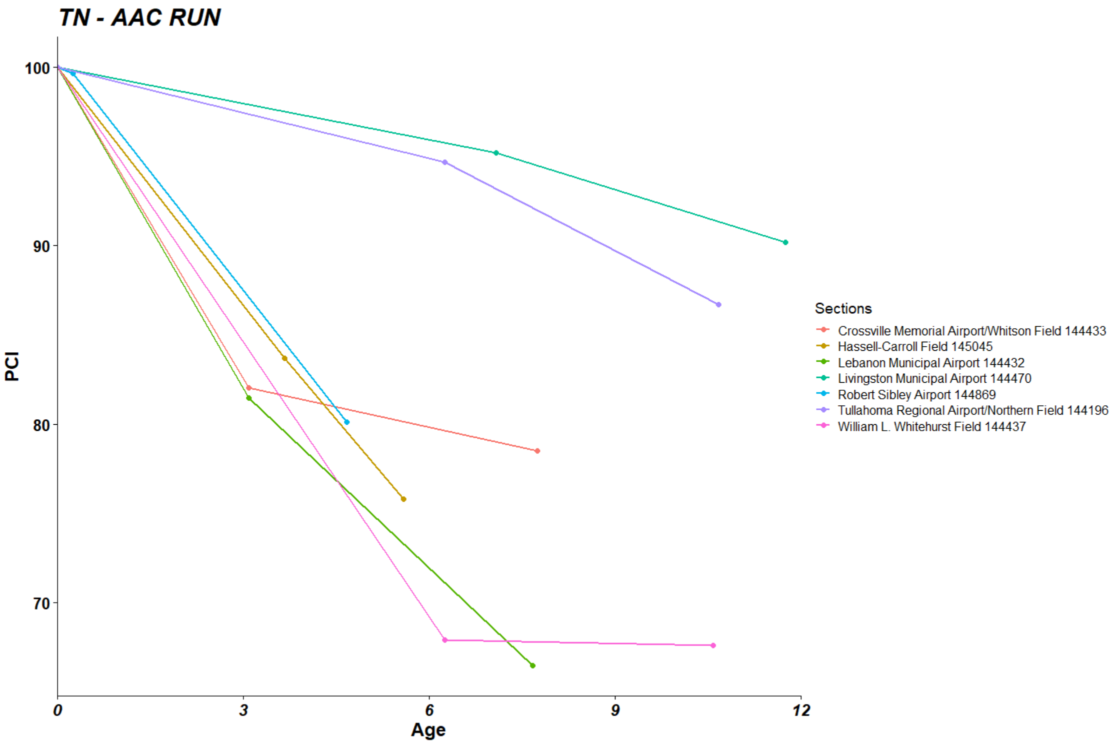

IN - AC TAX
PCI
100
90
80
70
60
Age
0
3
6
9
12
Sections
Anderson Municipal 147875
Angola - Tri-State Steuben County 147116
Connersville - Mettel Field 147243
Connersville - Mettel Field 147258
Connersville - Mettel Field 147507
Elkhart Municipal 147883
Elkhart Municipal 148084
Fort Wayne - Smith Field 147573
Fort Wayne - Smith Field 147578
French Lick Municipal 147640
Greencastle - Putnam County Regional 147603
Griffith - Merrillville 147666
Griffith - Merrillville 147809
Griffith - Merrillville 147810
Huntingburg 147037
Indianapolis Regional 146922
Kendallville Municipal 147700
Kendallville Municipal 148109
Kendallville Municipal 148110
Kendallville Municipal 148111
Knox - Starke County 147106
Knox - Starke County 147560
Knox - Starke County 147561
Logansport - Cass County 147712
Madison Municipal 147776
Madison Municipal 147777
Madison Municipal 147779
North Vernon Municipal 147582
North Vernon Municipal 147586
Portland Municipal 147534
Rochester - Fulton County 147659
Wabash Municipal 147129
Washington - Daviess County 147970


NM - AAC APR
PCI
100
75
50
25
Age
0
3
6
9
12
Sections
Cavern City Air Terminal (Carlsbad) 130484
Las Vegas Municipal Airport 130413
Las Vegas Municipal Airport 130705
Lea County Regional Airport (Hobbs) 130371
Lea County Regional Airport (Hobbs) 130489
Lea County Regional Airport (Hobbs) 130495
Taos Regional Airport 130510
Tatum Airport 130762


NM - AAC RUN
PCI
90
70
50
Age
0
3
6
9
12
Sections
Deming Municipal Airport 130434
Demonstration 130331
Double Eagle II Airport (Albuquerque) 130888
Four Corners Regional Airport (Farmington) 130799
Four Corners Regional Airport (Farmington) 130814
Las Vegas Municipal Airport 130513
Las Vegas Municipal Airport 130578
Los Alamos Airport 130417
Moriarty Airport 130742
Santa Fe Municipal Airport 130893
Shiprock Airstrip 130594
Tucumcari Municipal Airport 130676


NM - AC APR
PCI
100
75
50
25
Age
0
3
6
9
12
Sections
Clovis Municipal Airport 130895
Conchas Lake Airport (Conchas Dam) 130668
Dona Ana County Airport at Santa Teresa 130716
Double Eagle II Airport (Albuquerque) 130886
Fort Sumner Municipal Airport 130444
Four Corners Regional Airport (Farmington) 130791
Four Corners Regional Airport (Farmington) 130792
Four Corners Regional Airport (Farmington) 130795
Four Corners Regional Airport (Farmington) 130812
Gallup Municipal Airport 130776
Grants - Milan Municipal Airport 130651
Grants - Milan Municipal Airport 130652
Los Alamos Airport 130420
Moriarty Airport 130466
Moriarty Airport 130599
Navajo Lake Airport (Navajo Dam) 130817
Reserve Airport 130614
Santa Fe Municipal Airport 130914
Shiprock Airstrip 130653
Truth or Consequences Municipal Airport 130459
Vaughn Municipal Airport 130404


NV - AC RUN
PCI
100
90
80
70
60
0
3
6
9
12
Age
Sections
Battle Mountain Airport 151394
Battle Mountain Airport 151411
Battle Mountain Airport 151412
Carson City Airport 151320
Elko Regional Airport 151383
Lincoln County Airport 151368
Silver Springs Airport 151535
Tonopah Airport 151331
Yerington Municipal Airport 151515



APPENDIX B

AIRPORT IDENTIFIER ON CHARTS

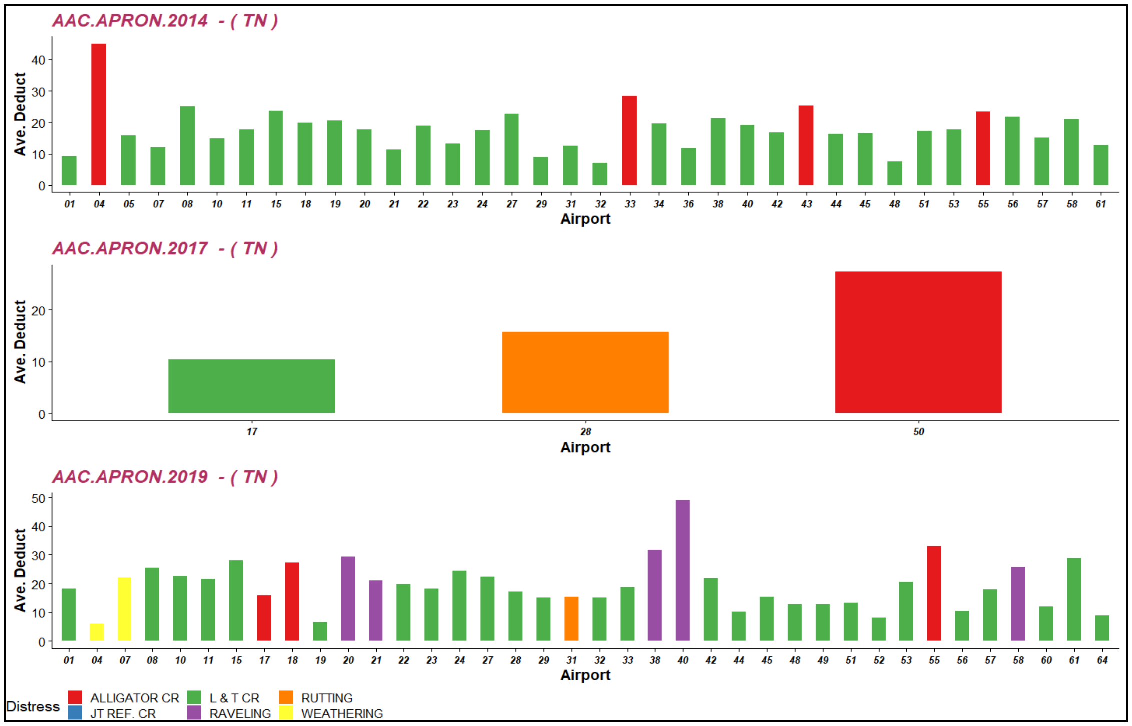
ID	TN	IN	NM	NV
01	Abernathy Field	Anderson Municipal	Alamogordo-White Sands Regional Airport	Alamo Landing Field
02	Arnold Field	Angola - Tri-State Steuben County	Alexander Municipal Airport (Belen)	Austin Airport
03	Benton County Airport	Auburn - DeKalb County	Angel Fire Airport	Battle Mountain Airport
04	Bomar Field-Shelbyville Municipal Airport	Bedford - Virgil I. Grissom Municipal	Artesia Municipal Airport	Beatty Airport
05	Campbell County Airport	Bloomington - Monroe County	Aztec Municipal Airport	Boulder City Airport
06	Carroll County Airport	Brazil - Clay County	Carrizozo Municipal Airport	Carson City Airport
07	Centerville Municipal Airport	Columbus Municipal	Cavern City Air Terminal (Carlsbad)	Derby Field
08	Charles W. Baker Field	Connersville - Mettel Field	Clayton Municipal Airpark	Elko Regional Airport
09	Collegedale Municipal Airport	Crawfordsville Municipal	Clovis Municipal Airport	Ely/Yelland Field
10	Covington Municipal Airport	Danville - Hendricks County	Conchas Lake Airport (Conchas Dam)	Eureka Airport
11	Crossville Memorial Airport/Whitson Field	Delphi Municipal	Crownpoint Airport	Fallon Municipal Airport
12	Dallas Bay Skypark Airport	Elkhart Municipal	Deming Municipal Airport	Hawthorne Airport
13	Dickson Municipal Airport	Fort Wayne - Smith Field	Demonstration	Jackpot/Hayden Field
14	Downtown Island Airport	Frankfort Municipal	Dona Ana County Airport at Santa Teresa	Lincoln County Airport
15	Dyersburg Municipal Airport	French Lick Municipal	Double Eagle II Airport (Albuquerque)	Mesquite Airport
16	Elizabethton Municipal Airport	Gary/Chicago International	Fort Sumner Municipal Airport	Minden - Tahoe Airport
17	Ellington Airport	Goshen Municipal	Four Corners Regional Airport (Farmington)	Owyhee Airport
18	Everett-Stewart Airport	Greencastle - Putnam County Regional	Gallup Municipal Airport	Silver Springs Airport
19	Fayette County Airport	Greensburg Municipal	Grant County Airport (Silver City)	Tonopah Airport
20	Fayetteville Municipal Airport	Griffith - Merrillville	Grants - Milan Municipal Airport	Wells Municipal/Harriet Field
21	Franklin County Airport	Huntingburg	Hatch Municipal Airport	Winnemucca Municipal Airport
22	Gatlinburg-Pigeon Forge Airport	Huntington Municipal	Jicarilla Apache Nation Airport (Dulce)	Yerington Municipal Airport
23	General Dewitt Spain Airport	Indianapolis Downtown Heliport	Las Cruces International Airport	
24	Gibson County Airport	Indianapolis Eagle Creek	Las Vegas Municipal Airport	

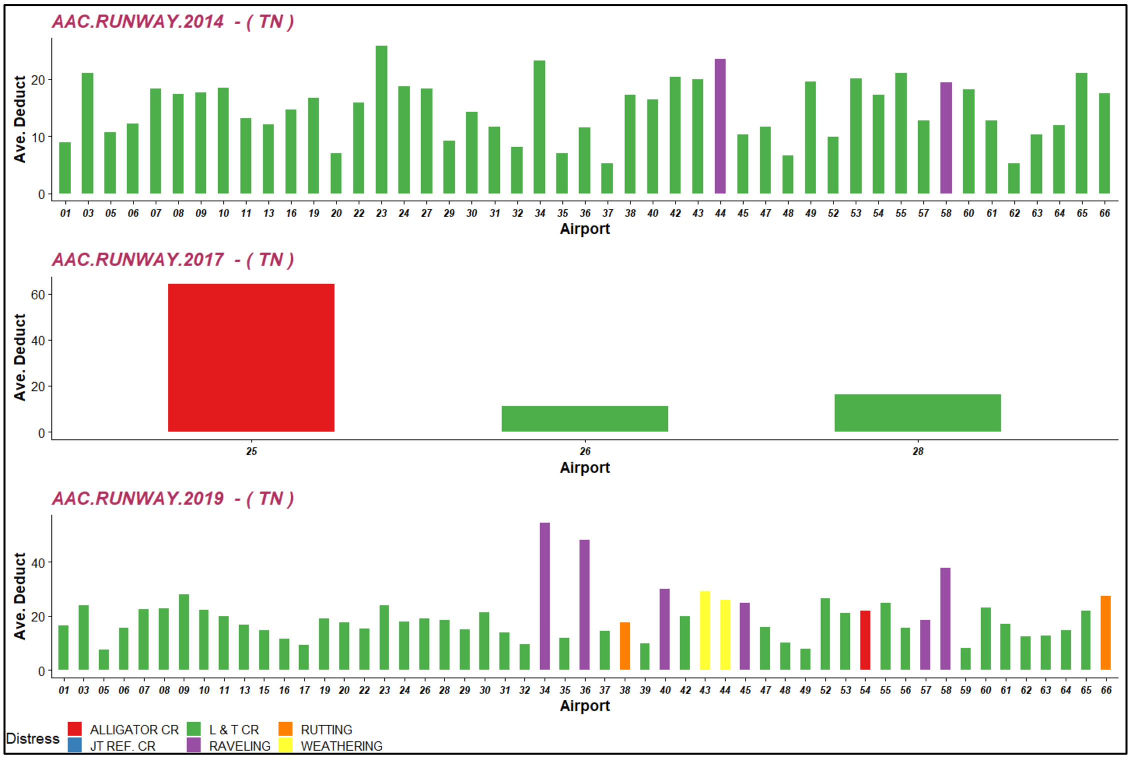
25	Greeneville-Green County Municipal Airport	Indianapolis Executive	Lea County (Jal) Airport	
26	Hassell-Carroll Field	Indianapolis Metropolitan	Lea County Regional Airport (Hobbs)	
27	Hawkins County Airport	Indianapolis Regional	Lordsburg Municipal Airport	
28	Henry County Airport	Indy South Greenwood Municipal	Los Alamos Airport	
29	Houston County Airport	Jeffersonville - Clark Regional	Moriarty Airport	
30	Humboldt Municipal Airport	Kendallville Municipal	Ohkay Owingeh Airport (Espanola)	
31	Humphreys County Airport	Kentland Municipal	Portales Municipal Airport	
32	Jackson County Airport	Knox - Starke County	Questa Municipal Airport Nr 2	
33	Jamestown Municipal Airport	Kokomo Municipal	Raton Municipal Airport/ Crews Field	
34	John A. Baker Field	La Porte Municipal	Reserve Airport	
35	Johnson County Airport	Lafayette - Purdue University	Roswell International Air Center Airport	
36	Lafayette Municipal Airport	Logansport - Cass County	Santa Fe Municipal Airport	
37	Lawrenceburg-Lawrence County Airport	Madison Municipal	Santa Rosa Route 66 Airport	
38	Lebanon Municipal Airport	Marion Municipal	Shiprock Airstrip	
39	Livingston Municipal Airport	Michigan City Municipal	Sierra Blanca Regional Airport (Ruidoso)	
40	Marion County Airport-Brown Field	Monticello - White County	Socorro Municipal Airport	
41	Mark Anton Airport	Muncie - Delaware County	Springer Municipal Airport	
42	Martin Campbell Field	New Castle - Henry County Municipal	Taos Regional Airport	
43	Maury County Airport	North Vernon Municipal	Tatum Airport	
44	McKellar-Sipes Regional Airport	Paoli Municipal	Truth or Consequences Municipal Airport	
45	McMinn County Airport	Peru Municipal	Tucumcari Municipal Airport	
46	Millington Regional Jetport	Plymouth Municipal	Vaughn Municipal Airport	
47	Monroe County Airport	Portland Municipal		
48	Moore-Murrell Field	Rensselaer - Jasper County		
49	Murfreesboro Municipal Airport	Richmond Municipal		
50	Music City Executive Airport	Rochester - Fulton County		

51	New Tazewell Municipal Airport	Seymour Municipal - Freeman Field		
52	Outlaw Field	Shelbyville Municipal		
53	Perry County Airport	Sheridan		
54	Portland Municipal Airport	Sullivan County		
55	Reelfoot Lake Airport	Tell City - Perry County Municipal		
56	Robert Sibley Airport	Terre Haute Regional		
57	Rockwood Municipal Airport	Valparaiso - Porter County Regional		
58	Scott Municipal Airport	Wabash Municipal		
59	Smithville Municipal Airport	Warsaw Municipal		
60	Smyrna Airport	Washington - Daviess County		
61	Springfield-Robertson County Airport	Winamac - Arens Field		
62	Tullahoma Regional Airport/Northern Field	Winchester - Randolph County		
63	Upper Cumberland Regional Airport			
64	Warren County Memorial Airport			
65	William L. Whitehurst Field			
66	Winchester Municipal Airport			

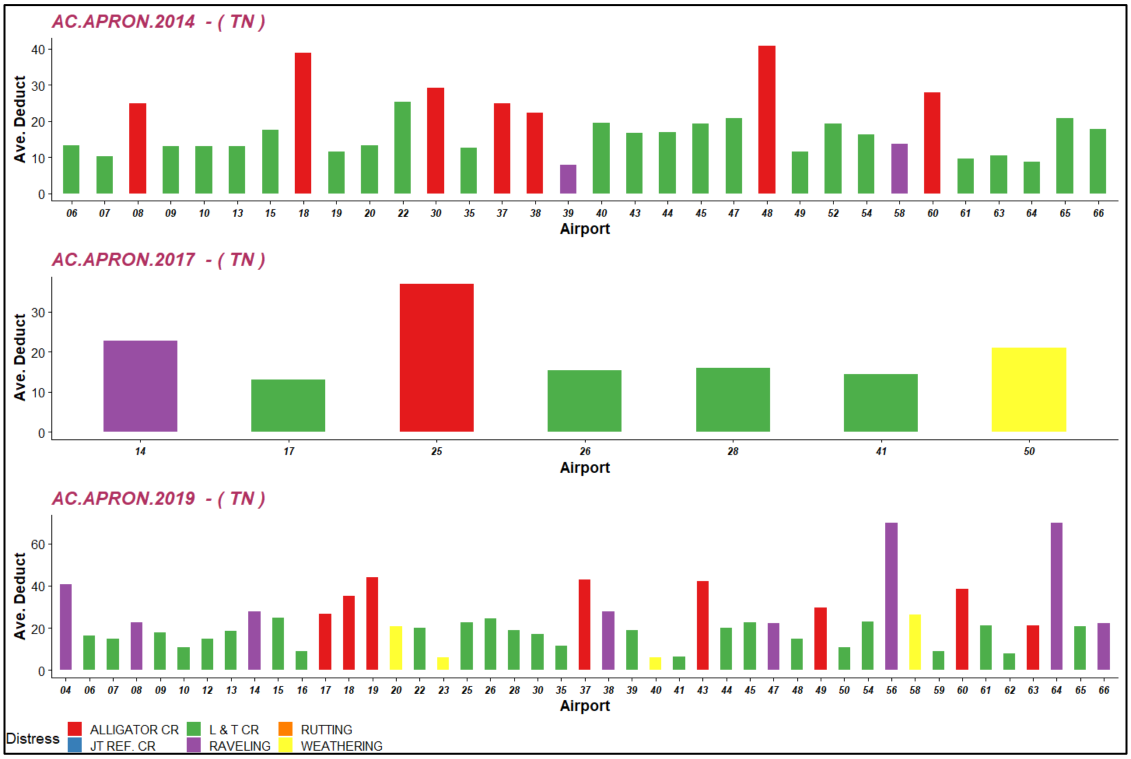
APPENDIX C

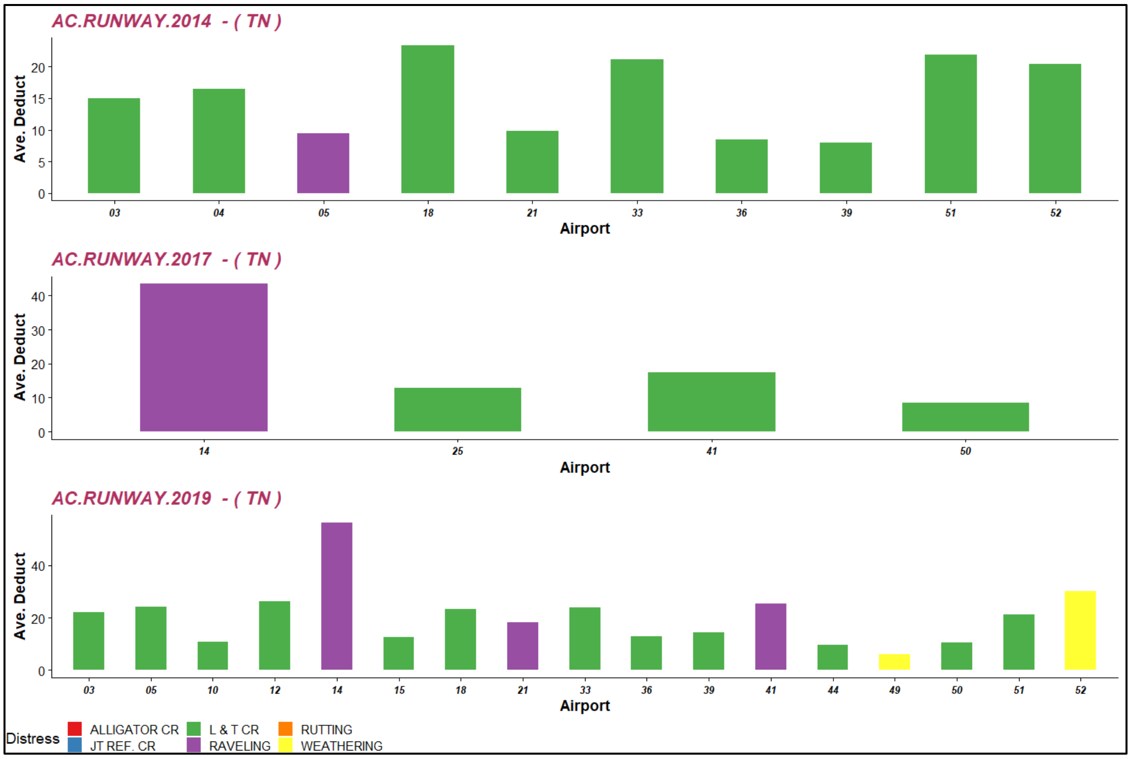
DOMINANT DISTRESS AT EACH AIRPORT


AAC.APRON.2014 - (TN)
Ave. Deduct
0
10
20
30
40
01 04 05 07 08 10 11 15 18 19 20 21 22 23 24 27 29 31 32 33 34 36 38 40 42 43 44 45 48 51 53 55 56 57 58 61
Airport
AAC.APRON.2017 - (TN)
Ave. Deduct
0
10
20
17 28 50
Airport
AAC.APRON.2019 - (TN)
Ave. Deduct
0
10
20
30
40
50
01 04 07 08 10 11 15 17 18 19 20 21 22 23 24 27 28 29 31 32 33 38 40 42 44 45 48 49 51 52 53 55 56 57 58 60 61 64
Airport
Distress
ALLIGATOR CR
JT REF. CR
L & T CR
RAVELING
RUTTING
WEATHERING

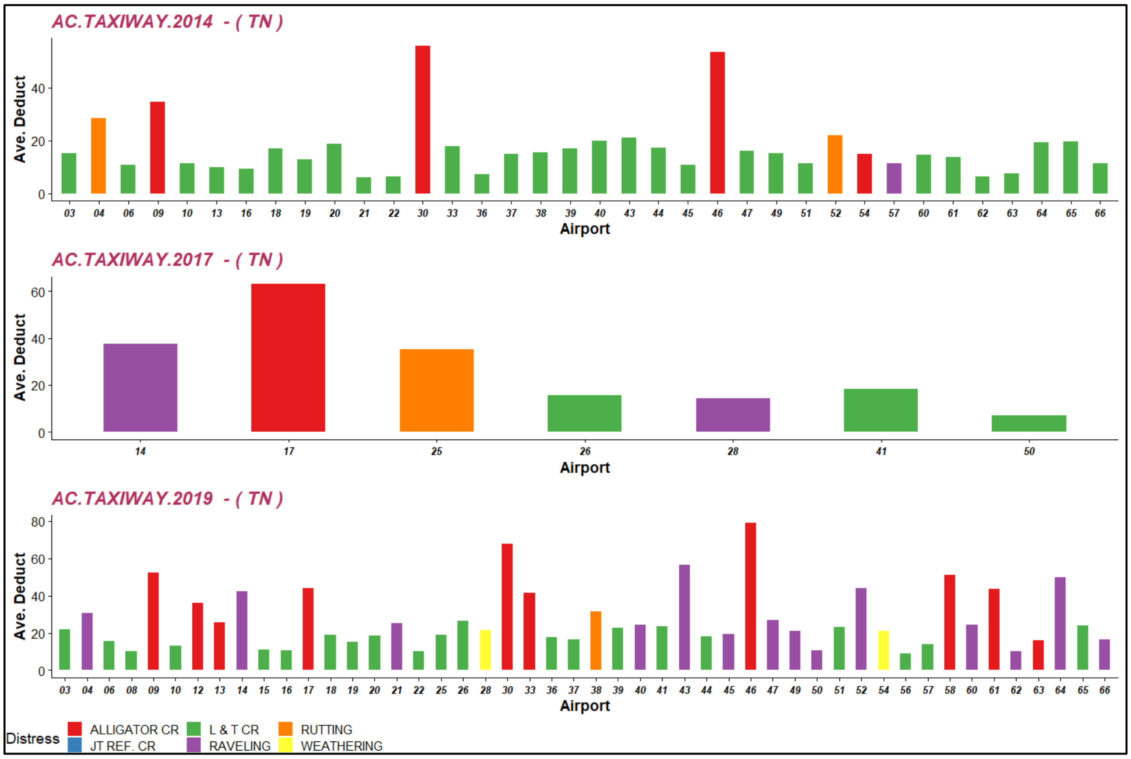

AAC.RUNWAY.2014 - (TN)
Ave. Deduct
0
10
20
01 03 05 06 07 08 09 10 11 13 16 19 20 22 23 24 27 29 30 31 32 34 35 36 37 38 40 42 43 44 45 47 48 49 52 53 54 55 57 58 60 61 62 63 64 65 66
Airport
AAC.RUNWAY.2017 - (TN)
Ave. Deduct
0
20
40
60
25 26 28
Airport
AAC.RUNWAY.2019 - (TN)
Ave. Deduct
0
20
40
01 03 05 06 07 08 09 10 11 13 15 16 17 19 20 22 23 24 26 28 29 30 31 32 34 35 36 37 38 39 40 42 43 44 45 47 48 49 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66
Airport
Distress
ALLIGATOR CR
JT REF. CR
L & T CR
RAVELING
RUTTING
WEATHERING


AAC.TAXIWAY.2014 - (TN)
Ave. Deduct
0
10
20
30
01 03 04 05 06 07 09 11 13 15 16 18 19 20 21 22 23 24 27 29 31 32 35 37 38 42 44 45 46 48 49 51 53 55 56 57 58 60 61 64 65
Airport
AAC.TAXIWAY.2017 - (TN)
Ave. Deduct
0
5
10
25
41
Airport
AAC.TAXIWAY.2019 - (TN)
Ave. Deduct
0
20
40
60
01 03 04 05 06 07 08 09 11 13 15 16 18 19 20 21 22 23 24 27 29 31 32 34 35 37 38 41 42 44 45 46 48 49 51 53 55 56 57 58 59 60 61 62 64 65
Airport
Distress
ALLIGATOR CR
JT REF. CR
L & T CR
RAVELING
RUTTING
WEATHERING

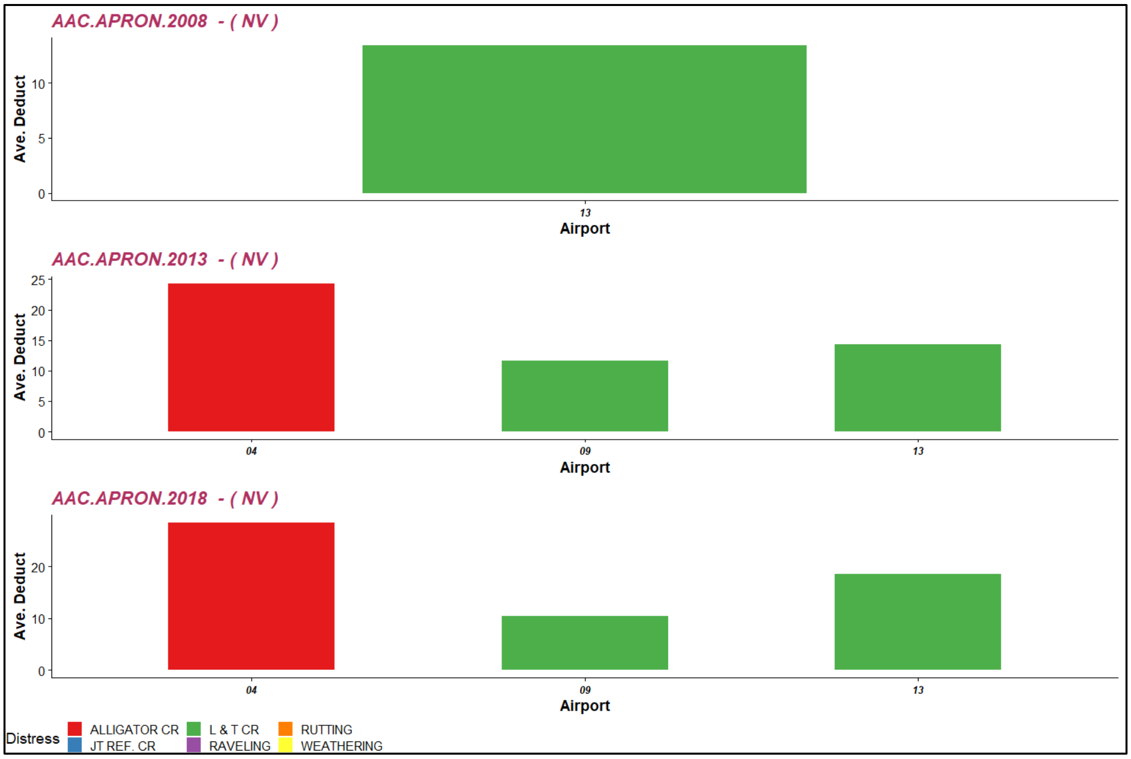

AC.APRON.2014 - (TN)
Ave. Deduct
0
10
20
30
40
06 07 08 09 10 13 15 18 19 20 22 30 35 37 38 39 40 43 44 45 47 48 49 52 54 58 60 61 63 64 65 66
Airport
AC.APRON.2017 - (TN)
Ave. Deduct
0
10
20
30
14 17 25 26 28 41 50
Airport
AC.APRON.2019 - (TN)
Ave. Deduct
0
20
40
60
04 06 07 08 09 10 12 13 14 15 16 17 18 19 20 22 23 25 26 28 30 35 37 38 39 40 41 43 44 45 47 48 49 50 54 56 58 59 60 61 62 63 64 65 66
Airport
Distress
ALLIGATOR CR
JT REF. CR
L & T CR
RAVELING
RUTTING
WEATHERING

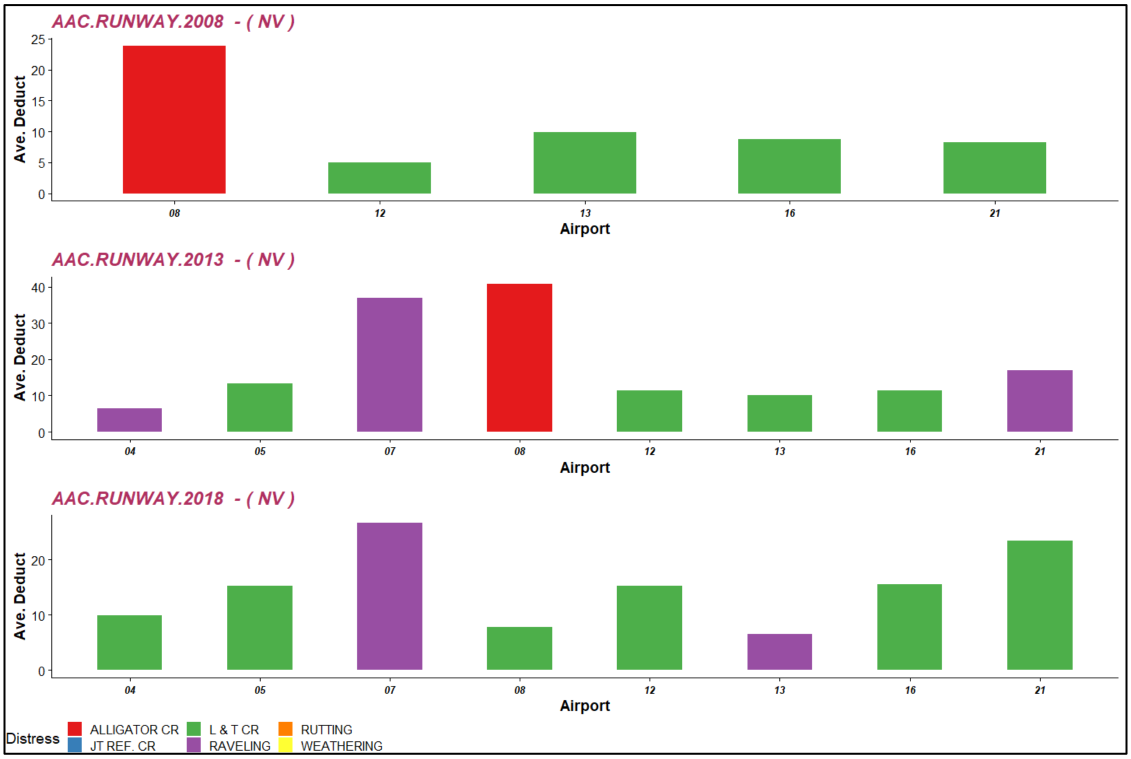


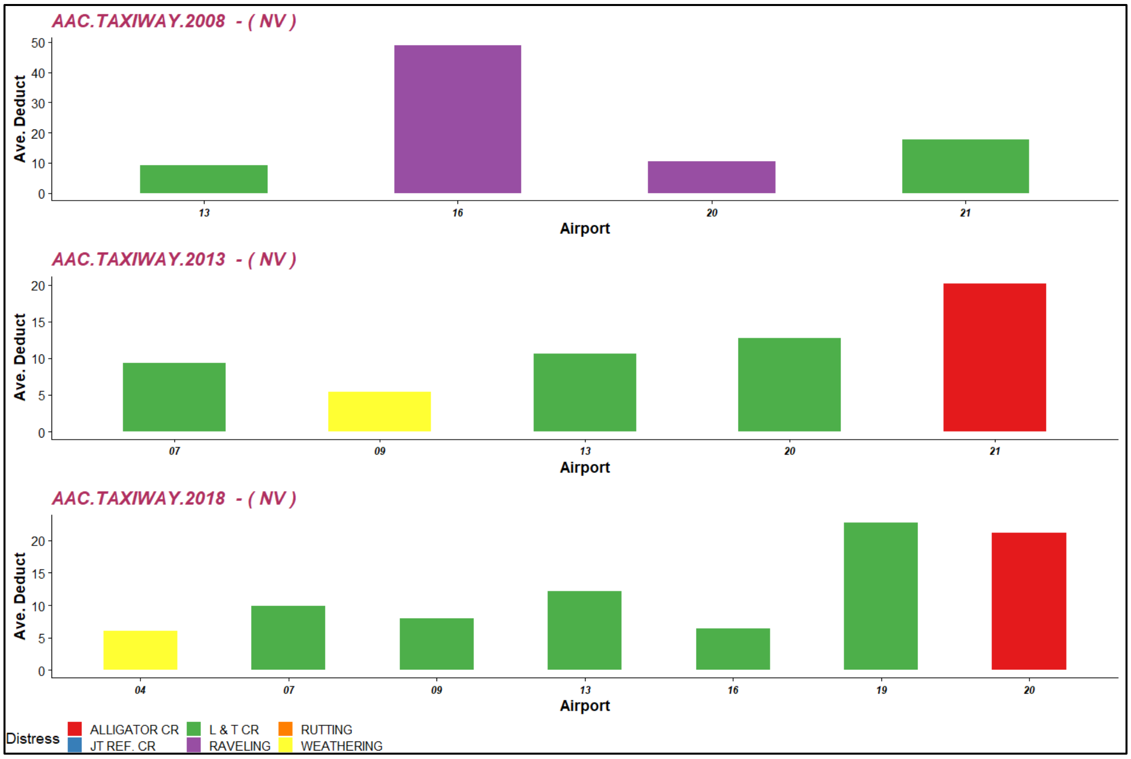
AC.RUNWAY.2014 - (TN)
Ave. Deduct
0
5
10
15
20
03
04
05
18
21
33
36
39
51
52
Airport
AC.RUNWAY.2017 - (TN)
Ave. Deduct
0
10
20
30
40
14
25
41
50
Airport
AC.RUNWAY.2019 - (TN)
Ave. Deduct
0
20
40
03
05
10
12
14
15
18
21
33
36
39
41
44
49
50
51
52
Airport
Distress
ALLIGATOR CR
JT REF. CR
L & T CR
RAVELING
RUTTING
WEATHERING

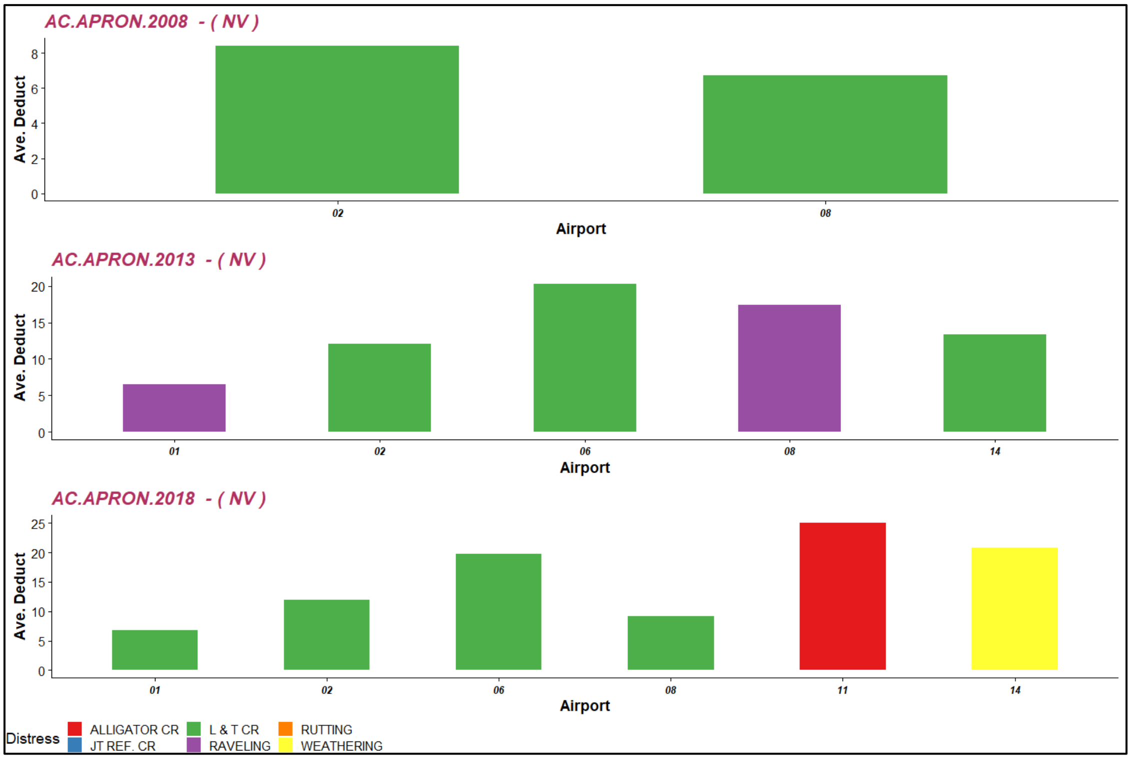


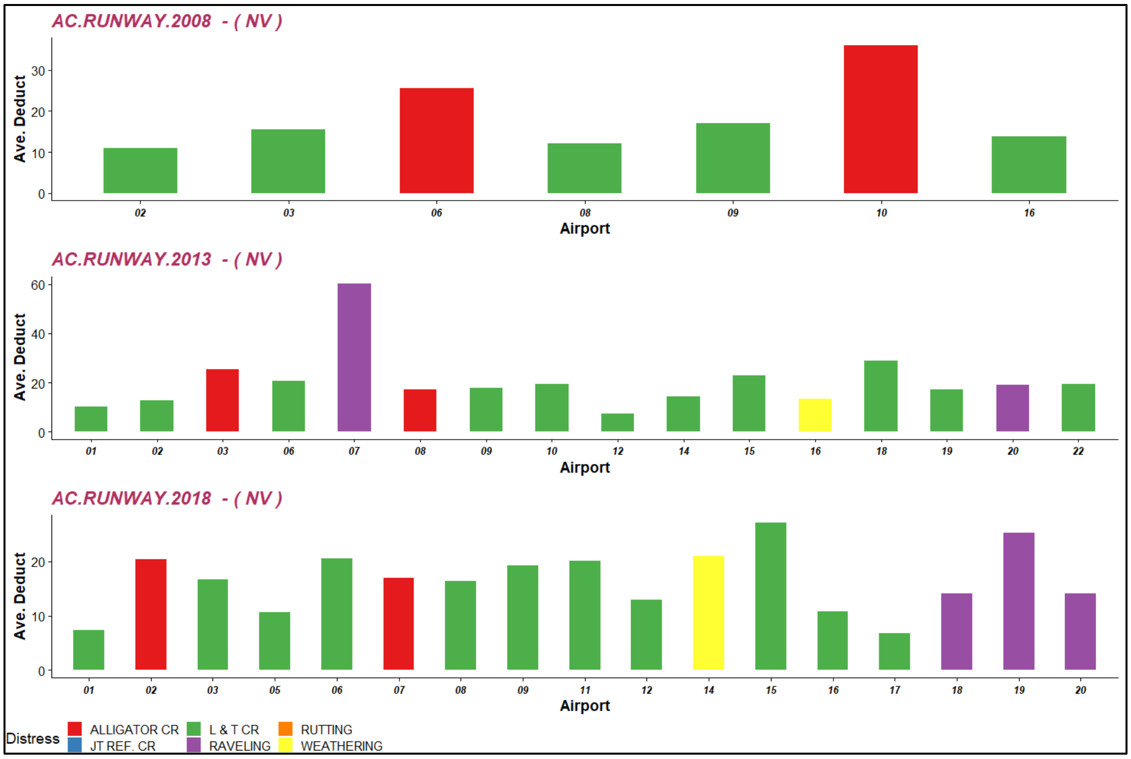
AC.TAXIWAY.2014 - (TN)
Ave. Deduct
0
20
40
03
04
06
09
10
13
16
18
19
20
21
22
30
33
36
37
38
39
40
43
44
45
46
47
49
51
52
54
57
60
61
62
63
64
65
66
Airport
AC.TAXIWAY.2017 - (TN)
Ave. Deduct
0
20
40
60
14
17
25
26
28
41
50
Airport
AC.TAXIWAY.2019 - (TN)
Ave. Deduct
0
20
40
60
80
03
04
06
08
09
10
12
13
14
15
16
17
18
19
20
21
22
25
26
28
30
33
36
37
38
39
40
41
43
44
45
46
47
49
50
51
52
54
56
57
58
60
61
62
63
64
65
66
Airport
Distress
ALLIGATOR CR
JT REF. CR
L & T CR
RAVELING
RUTTING
WEATHERING


AAC.APRON.2008 - (NV)
Ave. Deduct
0
5
10
13
Airport
AAC.APRON.2013 - (NV)
Ave. Deduct
0
5
10
15
20
25
04
09
13
Airport
AAC.APRON.2018 - (NV)
Ave. Deduct
0
10
20
04
09
13
Airport
Distress
ALLIGATOR CR
JT REF. CR
L & T CR
RAVELING
RUTTING
WEATHERING

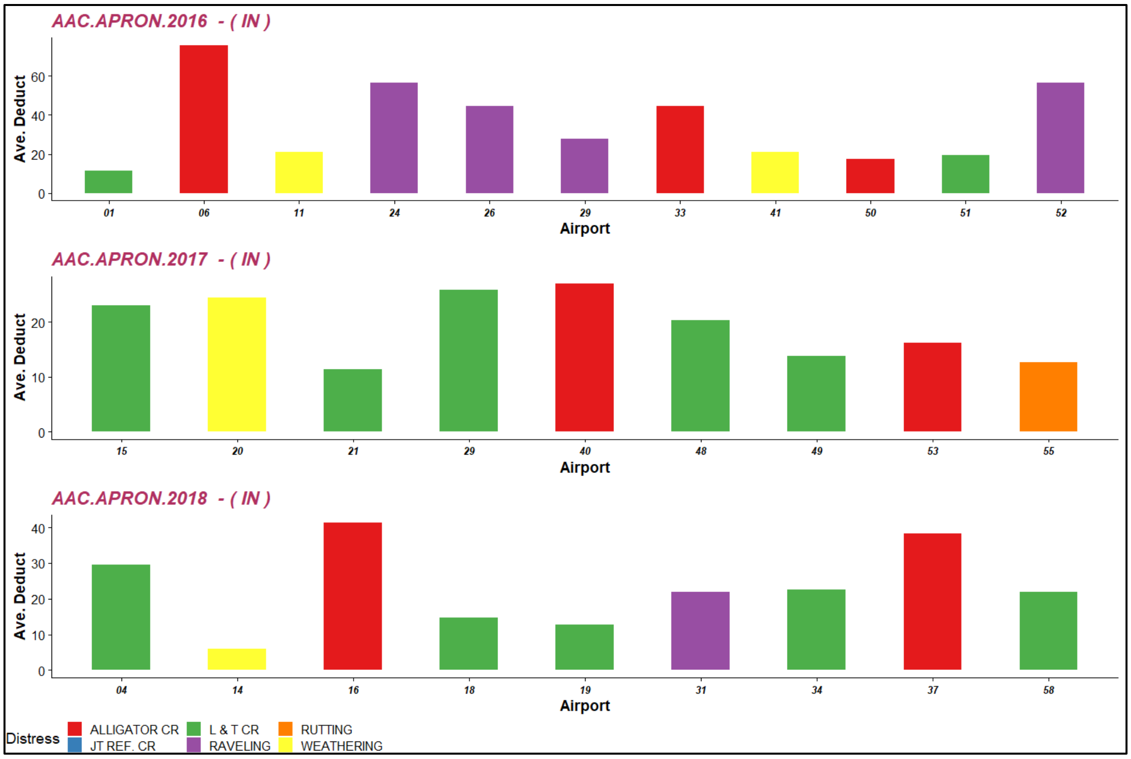

AAC.RUNWAY.2008 - (NV)
Ave. Deduct
0
5
10
15
20
25
08
12
13
16
21
Airport
AAC.RUNWAY.2013 - (NV)
Ave. Deduct
0
10
20
30
40
04
05
07
08
12
13
16
21
Airport
AAC.RUNWAY.2018 - (NV)
Ave. Deduct
0
10
20
04
05
07
08
12
13
16
21
Airport
Distress
ALLIGATOR CR
JT REF. CR
L & T CR
RAVELING
RUTTING
WEATHERING

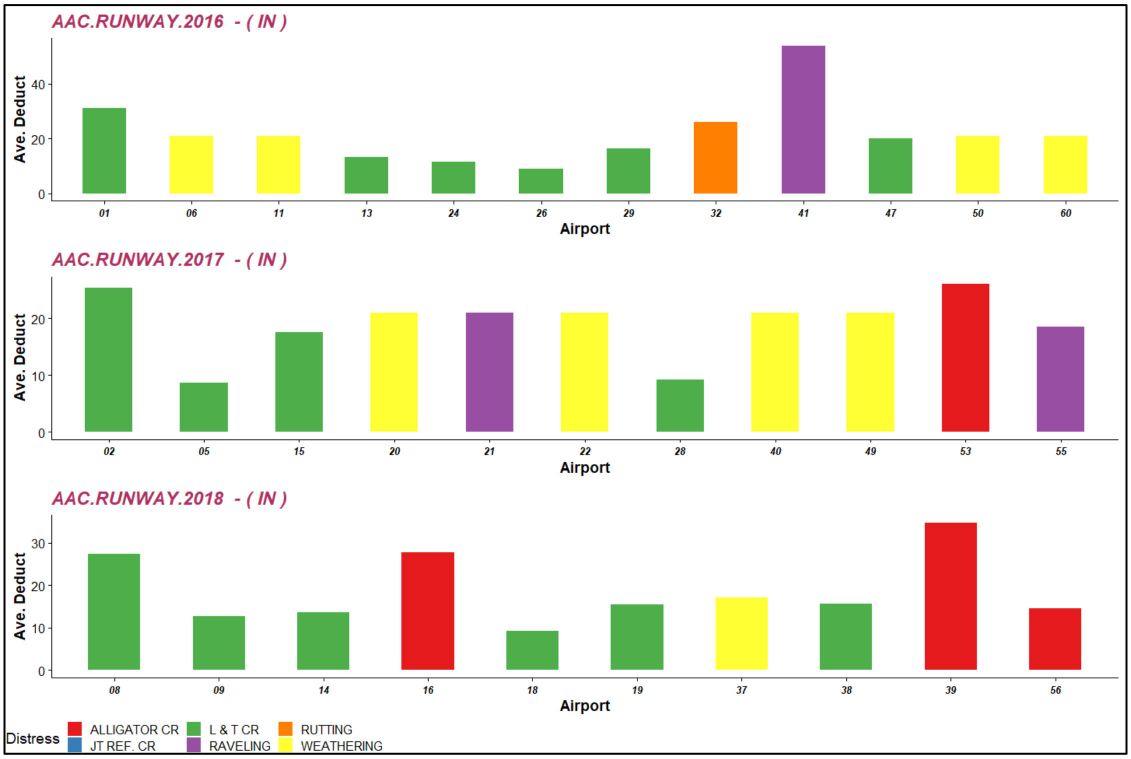

AAC.TAXIWAY.2008 - (NV)
Ave. Deduct
0
10
20
30
40
50
13
16
20
21
Airport
AAC.TAXIWAY.2013 - (NV)
Ave. Deduct
0
5
10
15
20
07
09
13
20
21
Airport
AAC.TAXIWAY.2018 - (NV)
Ave. Deduct
0
5
10
15
20
04
07
09
13
16
19
20
Airport
Distress
ALLIGATOR CR
JT REF. CR
L & T CR
RAVELING
RUTTING
WEATHERING

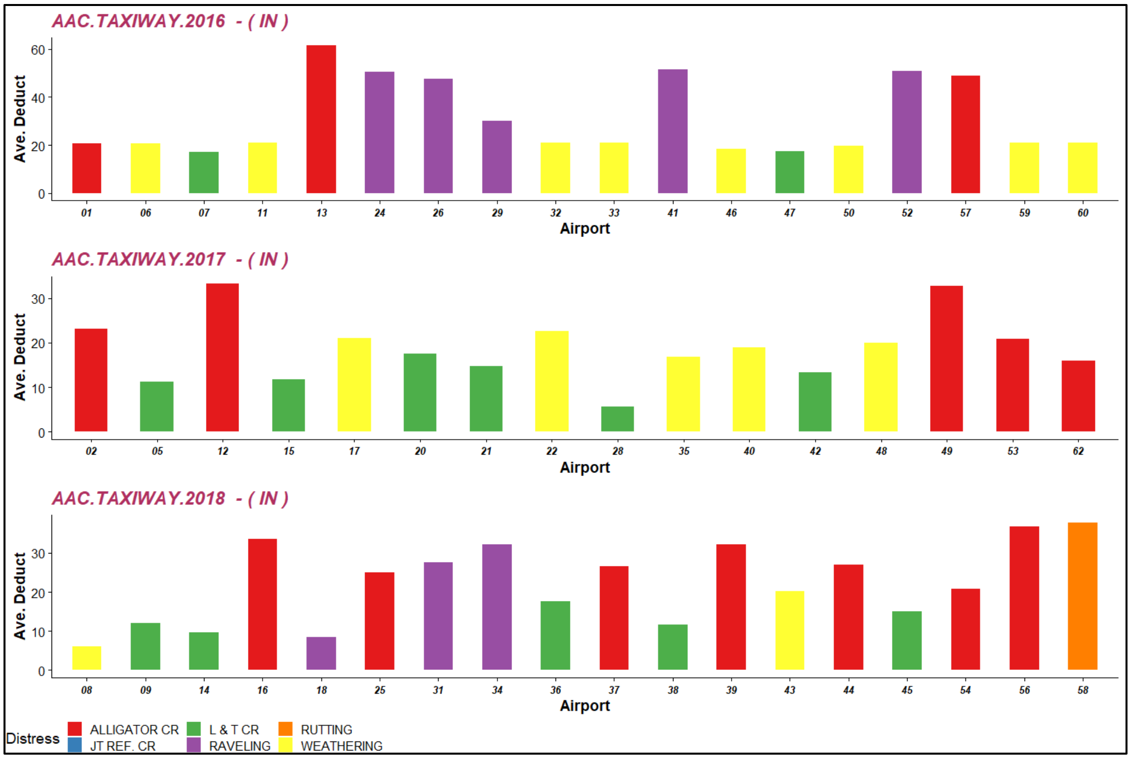

AC.APRON.2008 - (NV)
Ave. Deduct
0
2
4
6
8
02
08
Airport
AC.APRON.2013 - (NV)
Ave. Deduct
0
5
10
15
20
01
02
06
08
14
Airport
AC.APRON.2018 - (NV)
Ave. Deduct
0
5
10
15
20
25
01
02
06
08
11
14
Airport
Distress
ALLIGATOR CR
JT REF. CR
L & T CR
RAVELING
RUTTING
WEATHERING


AC.RUNWAY.2008 - (NV)
Ave. Deduct
0
10
20
30
02
03
06
08
09
10
16
Airport
AC.RUNWAY.2013 - (NV)
Ave. Deduct
0
20
40
60
01
02
03
06
07
08
09
10
12
14
15
16
18
19
20
22
Airport
AC.RUNWAY.2018 - (NV)
Ave. Deduct
0
10
20
01
02
03
05
06
07
08
09
11
12
14
15
16
17
18
19
20
Airport
Distress
ALLIGATOR CR
JT REF. CR
L & T CR
RAVELING
RUTTING
WEATHERING

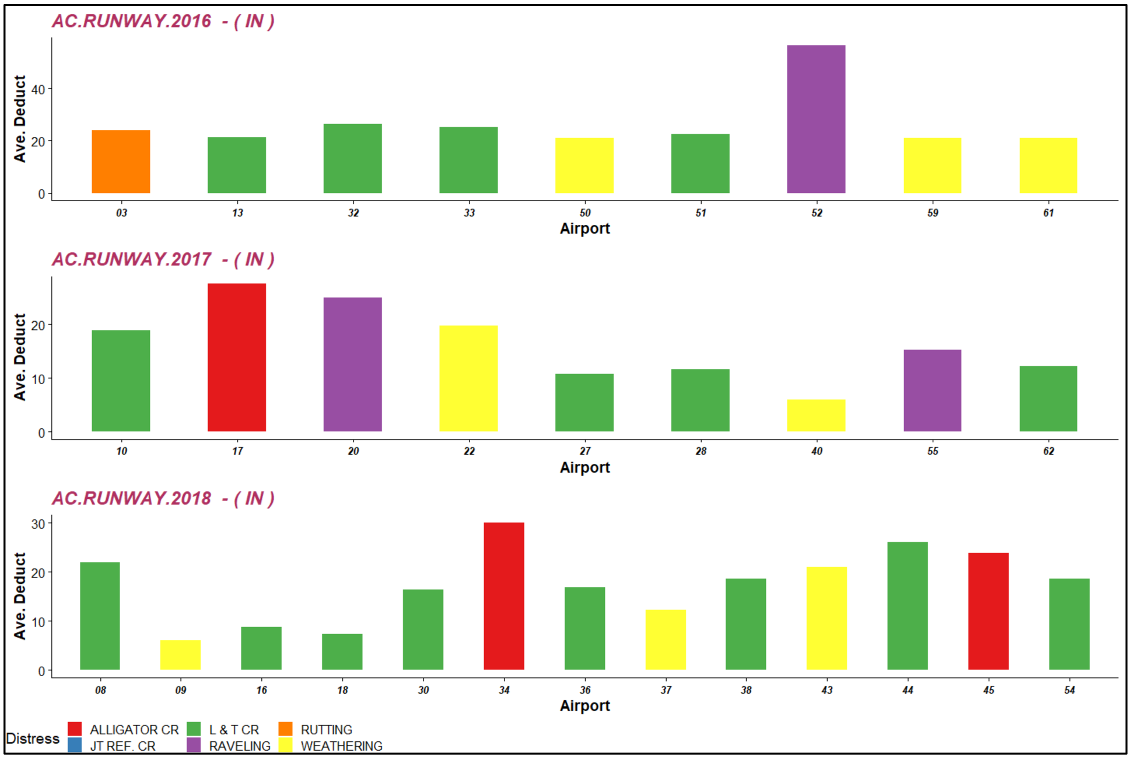

AC.TAXIWAY.2008 - (NV)
Ave. Deduct
0
10
20
30
40
50
02
03
06
09
10
12
13
Airport
AC.TAXIWAY.2013 - (NV)
Ave. Deduct
0
10
20
30
40
50
01
02
03
05
06
08
09
10
12
13
14
15
16
18
19
22
Airport
AC.TAXIWAY.2018 - (NV)
Ave. Deduct
0
20
40
01
02
03
05
06
08
09
10
11
12
13
14
15
16
18
19
Airport
Distress
ALLIGATOR CR
JT REF. CR
L & T CR
RAVELING
RUTTING
WEATHERING


AAC.APRON.2016 - (IN)
Ave. Deduct
0
20
40
60
01
06
11
24
26
29
33
41
50
51
52
Airport
AAC.APRON.2017 - (IN)
Ave. Deduct
0
10
20
15
20
21
29
40
48
49
53
55
Airport
AAC.APRON.2018 - (IN)
Ave. Deduct
0
10
20
30
40
04
14
16
18
19
31
34
37
58
Airport
Distress
ALLIGATOR CR
JT REF. CR
L & T CR
RAVELING
RUTTING
WEATHERING

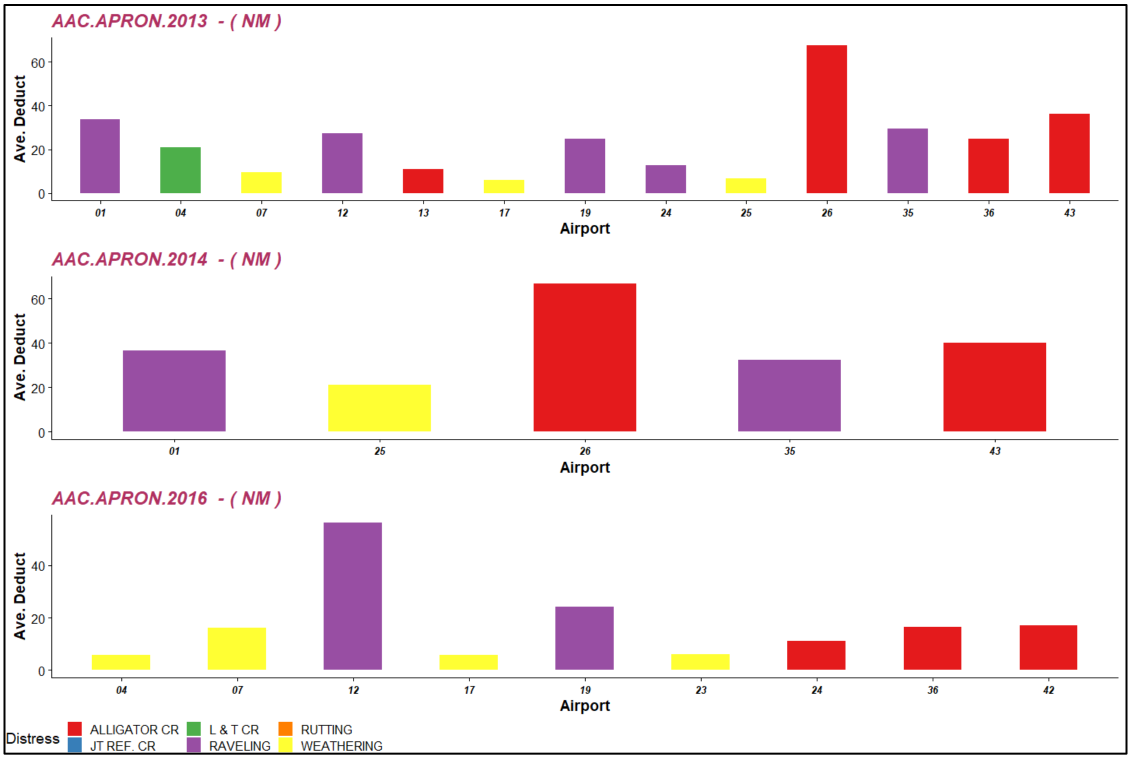

AAC.RUNWAY.2016 - (IN)
Ave. Deduct
0
20
40
01
06
11
13
24
26
29
32
41
47
50
60
Airport
AAC.RUNWAY.2017 - (IN)
Ave. Deduct
0
10
20
02
05
15
20
21
22
28
40
49
53
55
Airport
AAC.RUNWAY.2018 - (IN)
Ave. Deduct
0
10
20
30
08
09
14
16
18
19
37
38
39
56
Airport
Distress
ALLIGATOR CR
JT REF. CR
L & T CR
RAVELING
RUTTING
WEATHERING

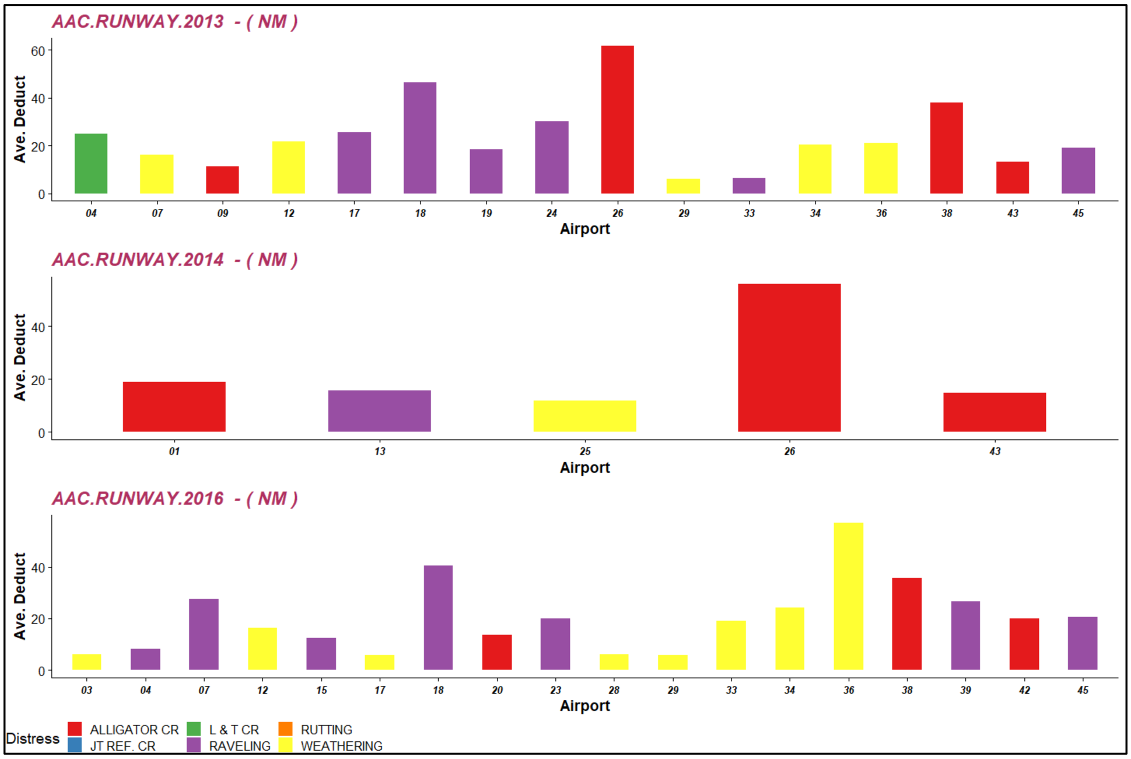

AAC.TAXIWAY.2016 - (IN)
Ave. Deduct
0
20
40
60
01
06
07
11
13
24
26
29
32
33
41
46
47
50
52
57
59
60
Airport
AAC.TAXIWAY.2017 - (IN)
Ave. Deduct
0
10
20
30
02
05
12
15
17
20
21
22
28
35
40
42
48
49
53
62
Airport
AAC.TAXIWAY.2018 - (IN)
Ave. Deduct
0
10
20
30
08
09
14
16
18
25
31
34
36
37
38
39
43
44
45
54
56
58
Airport
Distress
ALLIGATOR CR
JT REF. CR
L & T CR
RAVELING
RUTTING
WEATHERING

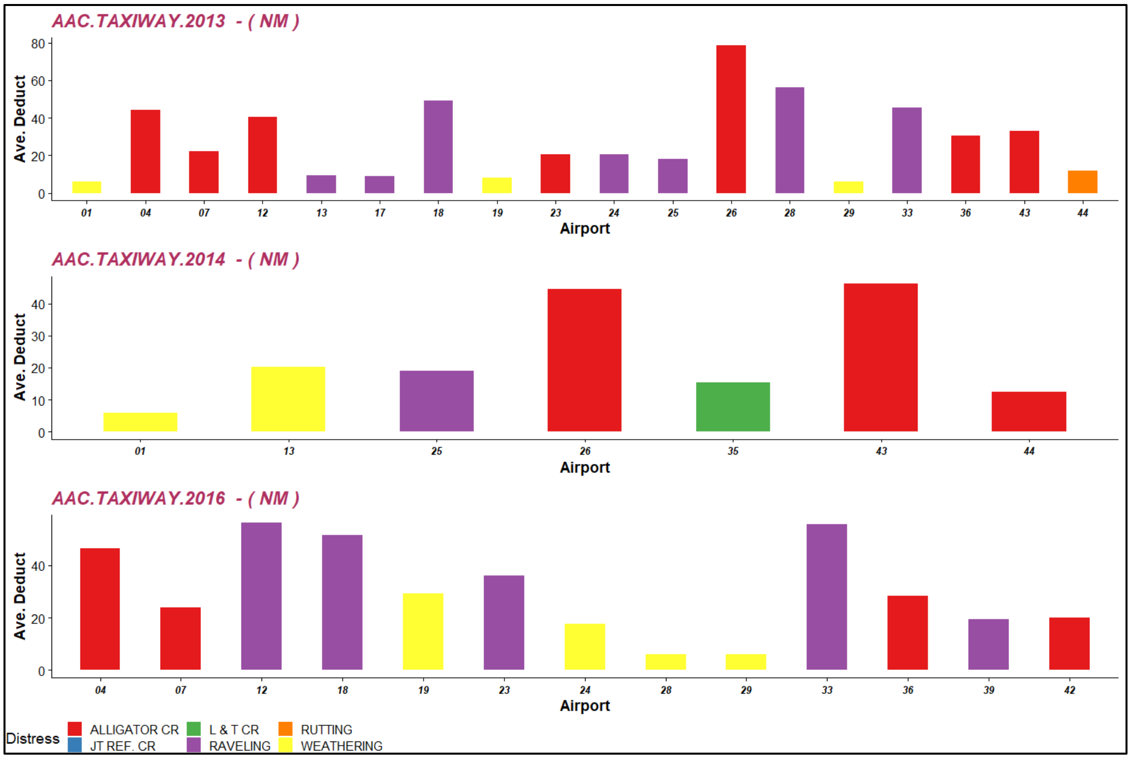

AC.APRON.2016 - (IN)
Ave. Deduct
0
20
40
60
03
07
13
24
29
32
33
46
47
51
59
60
61
Airport
AC.APRON.2017 - (IN)
Ave. Deduct
0
20
40
60
05
12
20
21
23
28
29
40
53
55
Airport
AC.APRON.2018 - (IN)
Ave. Deduct
0
10
20
30
40
04
14
18
25
30
31
34
36
37
38
43
44
45
54
56
58
Airport
Distress
ALLIGATOR CR
JT REF. CR
L & T CR
RAVELING
RUTTING
WEATHERING

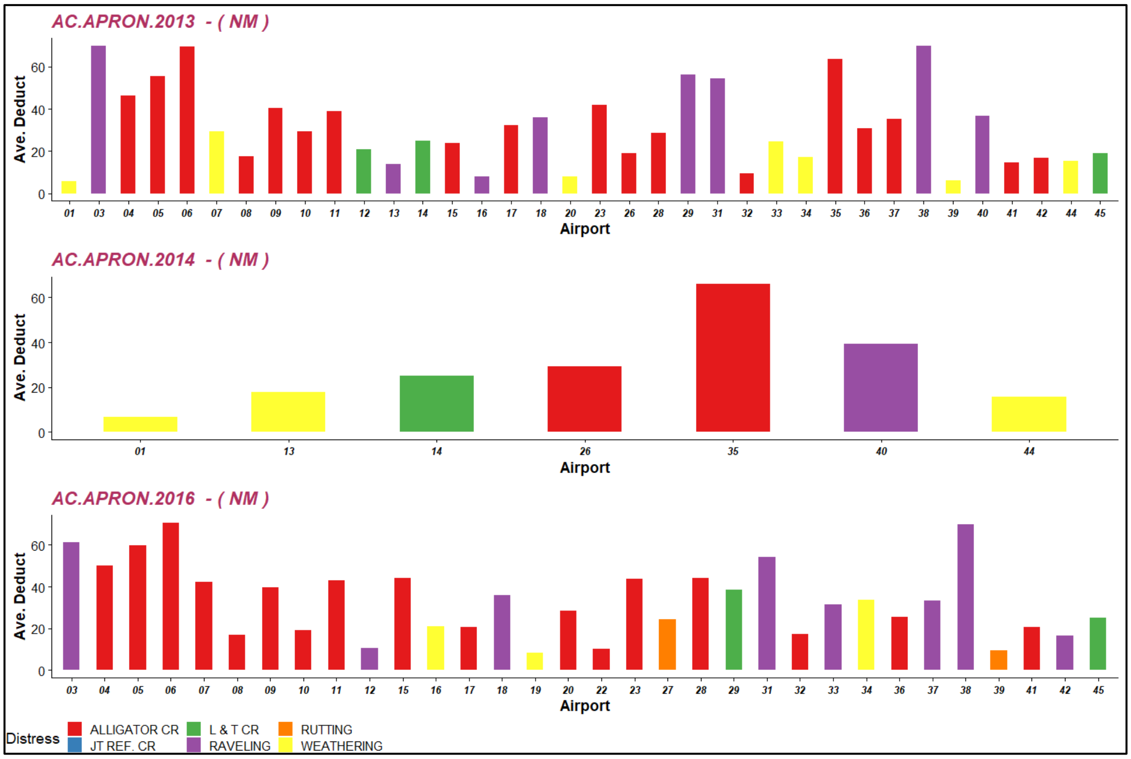

AC.RUNWAY.2016 - (IN)
Ave. Deduct
0
20
40
03
13
32
33
50
51
52
59
61
Airport
AC.RUNWAY.2017 - (IN)
Ave. Deduct
0
10
20
10
17
20
22
27
28
40
55
62
Airport
AC.RUNWAY.2018 - (IN)
Ave. Deduct
0
10
20
30
08
09
16
18
30
34
36
37
38
43
44
45
54
Airport
Distress
ALLIGATOR CR
JT REF. CR
L & T CR
RAVELING
RUTTING
WEATHERING

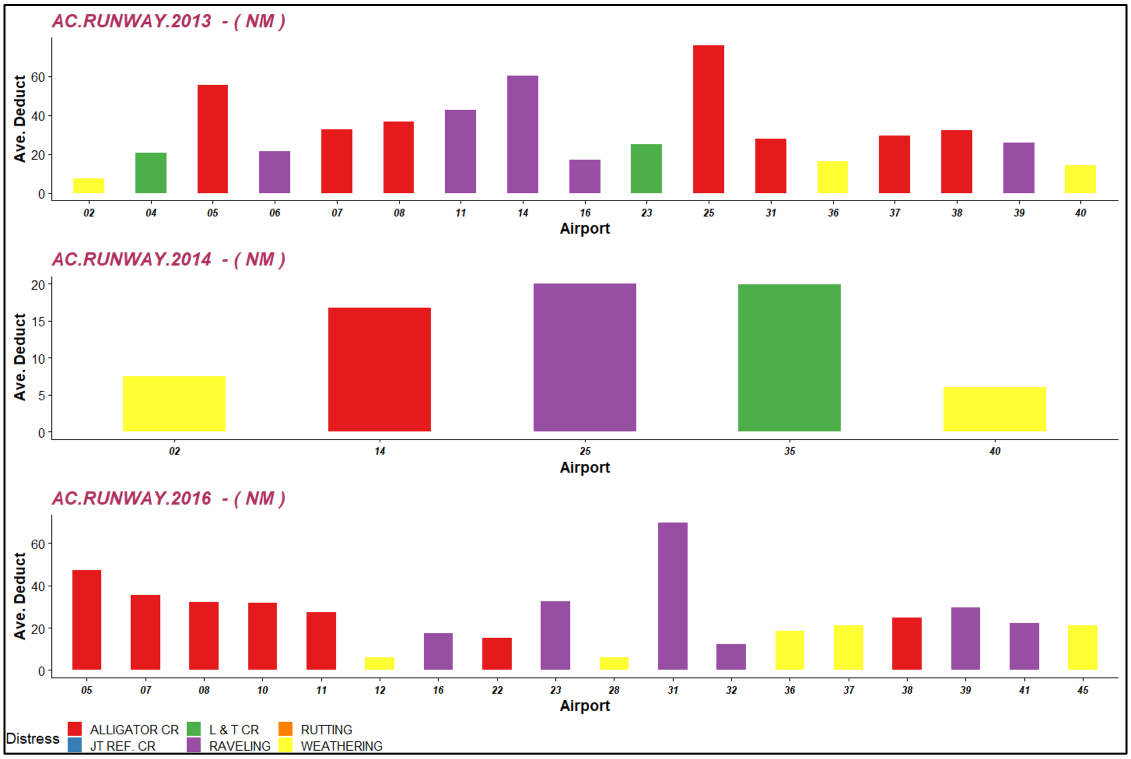

AC.TAXIWAY.2016 - (IN)
Ave. Deduct
0
20
40
01
03
07
13
26
29
32
33
47
50
51
52
57
59
60
61
Airport
AC.TAXIWAY.2017 - (IN)
Ave. Deduct
0
10
20
30
02
05
10
12
15
17
20
21
22
27
28
40
42
48
49
53
55
62
Airport
AC.TAXIWAY.2018 - (IN)
Ave. Deduct
0
10
20
30
08
09
14
16
18
25
30
31
34
36
37
38
39
43
45
54
56
58
Airport
Distress
ALLIGATOR CR
JT REF. CR
L & T CR
RAVELING
RUTTING
WEATHERING

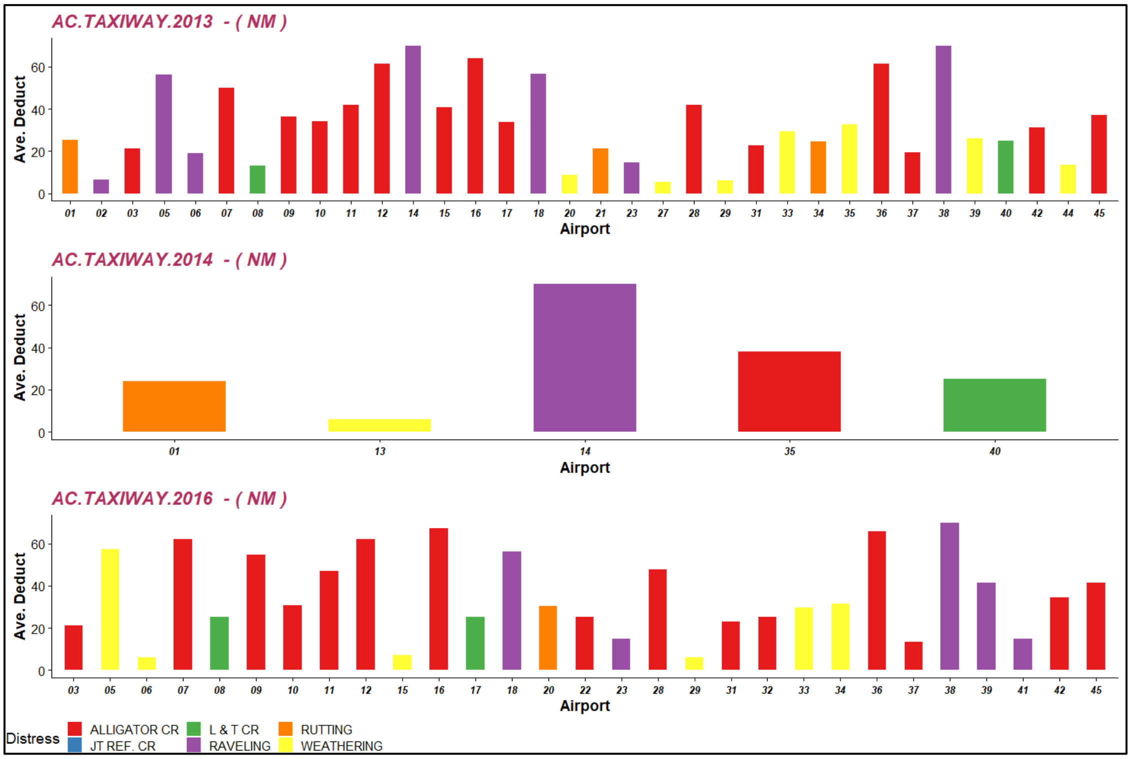

AAC.APRON.2013 - (NM)
Ave. Deduct
0
20
40
60
01
04
07
12
13
17
19
24
25
26
35
36
43
Airport
AAC.APRON.2014 - (NM)
Ave. Deduct
0
20
40
60
01
25
26
35
43
Airport
AAC.APRON.2016 - (NM)
Ave. Deduct
0
20
40
04
07
12
17
19
23
24
36
42
Airport
Distress
ALLIGATOR CR
JT REF. CR
L & T CR
RAVELING
RUTTING
WEATHERING


AAC.RUNWAY.2013 - (NM)
Ave. Deduct
0
20
40
60
04
07
09
12
17
18
19
24
26
29
33
34
36
38
43
45
Airport
AAC.RUNWAY.2014 - (NM)
Ave. Deduct
0
20
40
01
13
25
26
43
Airport
AAC.RUNWAY.2016 - (NM)
Ave. Deduct
0
20
40
03
04
07
12
15
17
18
20
23
28
29
33
34
36
38
39
42
45
Airport
Distress
ALLIGATOR CR
JT REF. CR
L & T CR
RAVELING
RUTTING
WEATHERING


AAC.TAXIWAY.2013 - (NM)
Ave. Deduct
0
20
40
60
80
01 04 07 12 13 17 18 19 23 24 25 26 28 29 33 36 43 44
Airport
AAC.TAXIWAY.2014 - (NM)
Ave. Deduct
0
10
20
30
40
01 13 25 26 35 43 44
Airport
AAC.TAXIWAY.2016 - (NM)
Ave. Deduct
0
20
40
04 07 12 18 19 23 24 28 29 33 36 39 42
Airport
Distress
ALLIGATOR CR
JT REF. CR
L & T CR
RAVELING
RUTTING
WEATHERING

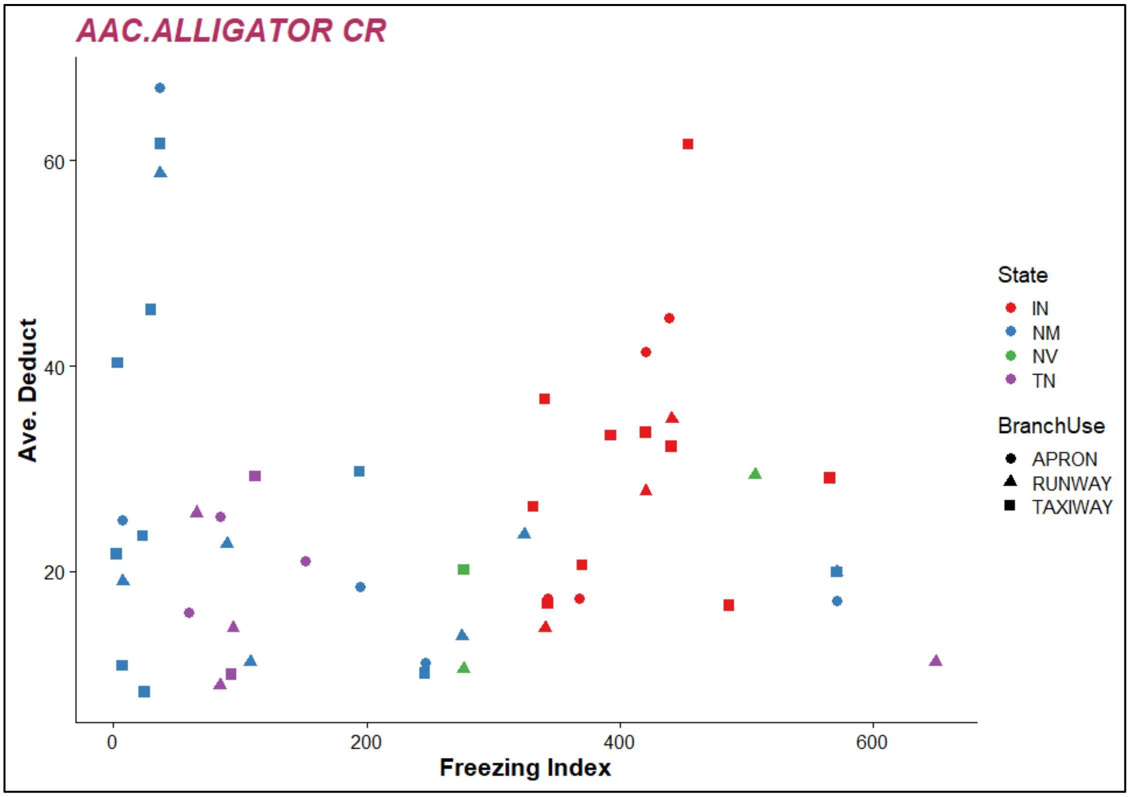

AC.APRON.2013 - (NM)
Ave. Deduct
0
20
40
60
01 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 20 23 26 28 29 31 32 33 34 35 36 37 38 39 40 41 42 44 45
Airport
AC.APRON.2014 - (NM)
Ave. Deduct
0
20
40
60
01 13 14 26 35 40 44
Airport
AC.APRON.2016 - (NM)
Ave. Deduct
0
20
40
60
03 04 05 06 07 08 09 10 11 12 15 16 17 18 19 20 22 23 27 28 29 31 32 33 34 36 37 38 39 41 42 45
Airport
Distress
ALLIGATOR CR
JT REF. CR
L & T CR
RAVELING
RUTTING
WEATHERING

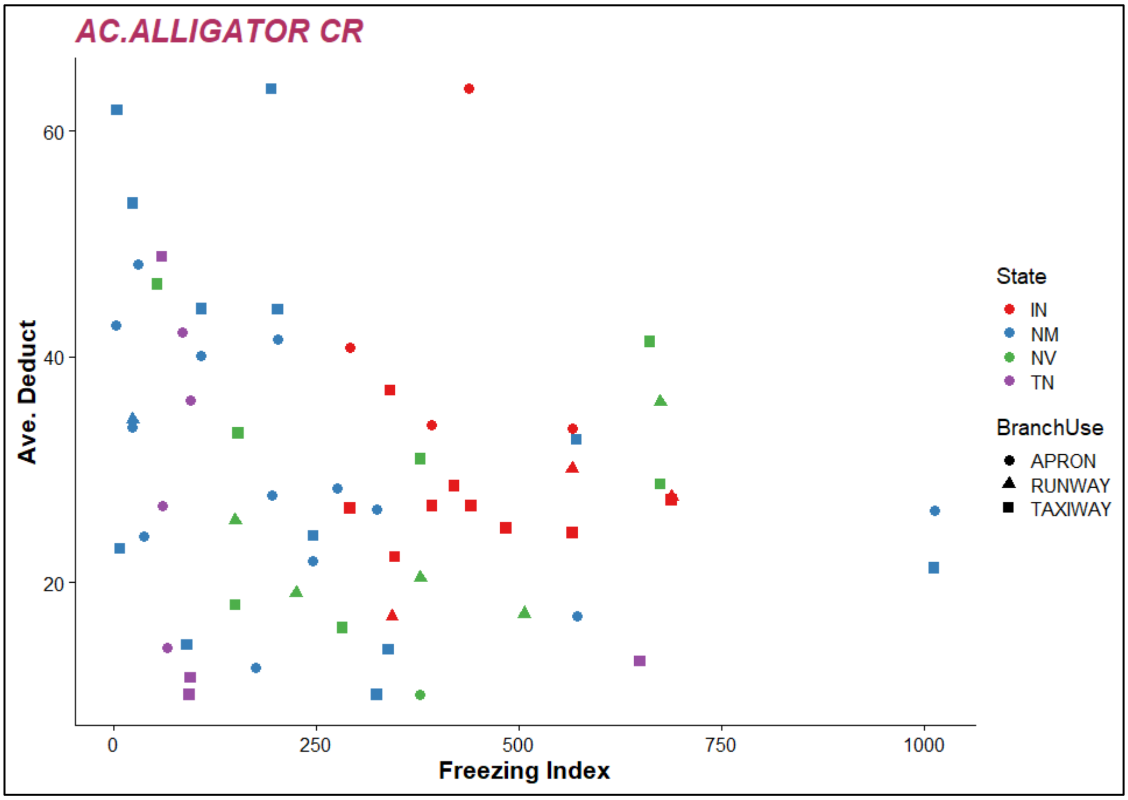

AC.RUNWAY.2013 - (NM)
Ave. Deduct
0
20
40
60
02
04
05
06
07
08
11
14
16
23
25
31
36
37
38
39
40
Airport
AC.RUNWAY.2014 - (NM)
Ave. Deduct
0
5
10
15
20
02
14
25
35
40
Airport
AC.RUNWAY.2016 - (NM)
Ave. Deduct
0
20
40
60
05
07
08
10
11
12
16
22
23
28
31
32
36
37
38
39
41
45
Airport
Distress
ALLIGATOR CR
JT REF. CR
L & T CR
RAVELING
RUTTING
WEATHERING

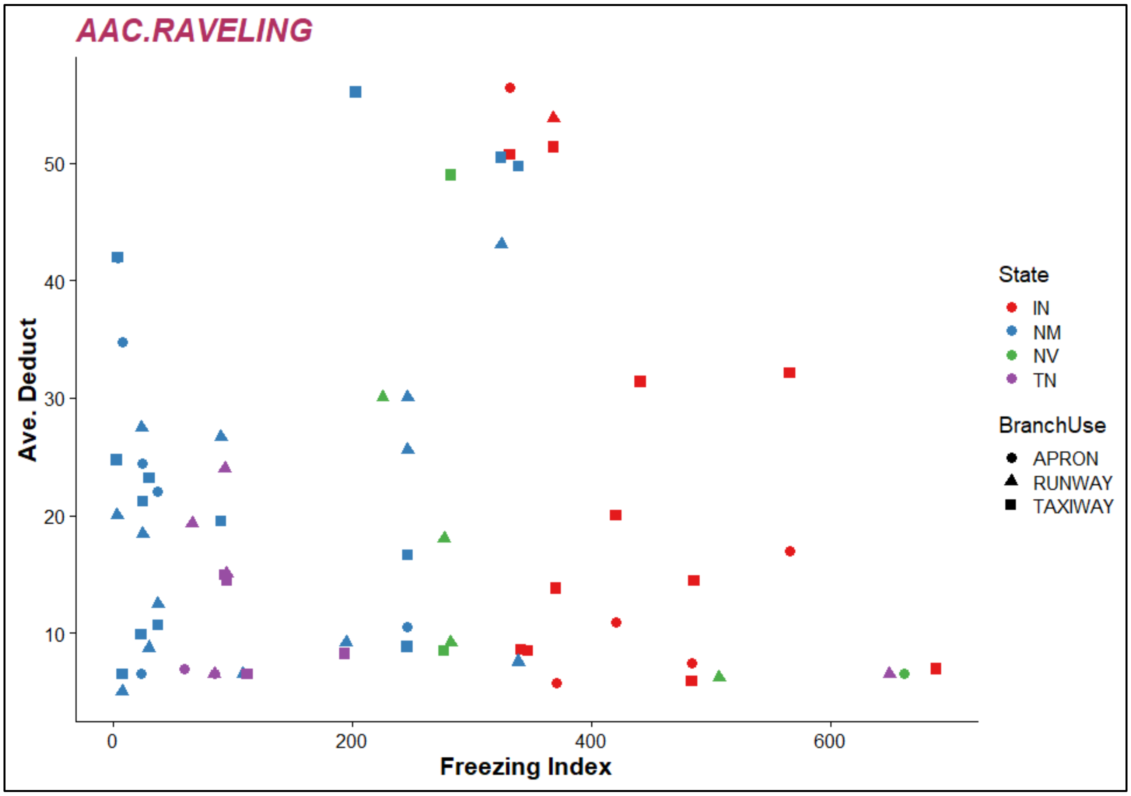

AC.TAXIWAY.2013 - (NM)
Ave. Deduct
0
20
40
60
01
02
03
05
06
07
08
09
10
11
12
14
15
16
17
18
20
21
23
27
28
29
31
33
34
35
36
37
38
39
40
42
44
45
Airport
AC.TAXIWAY.2014 - (NM)
Ave. Deduct
0
20
40
60
01
13
14
35
40
Airport
AC.TAXIWAY.2016 - (NM)
Ave. Deduct
0
20
40
60
03
05
06
07
08
09
10
11
12
15
16
17
18
20
22
23
28
29
31
32
33
34
36
37
38
39
41
42
45
Airport
Distress
ALLIGATOR CR
JT REF. CR
L & T CR
RAVELING
RUTTING
WEATHERING

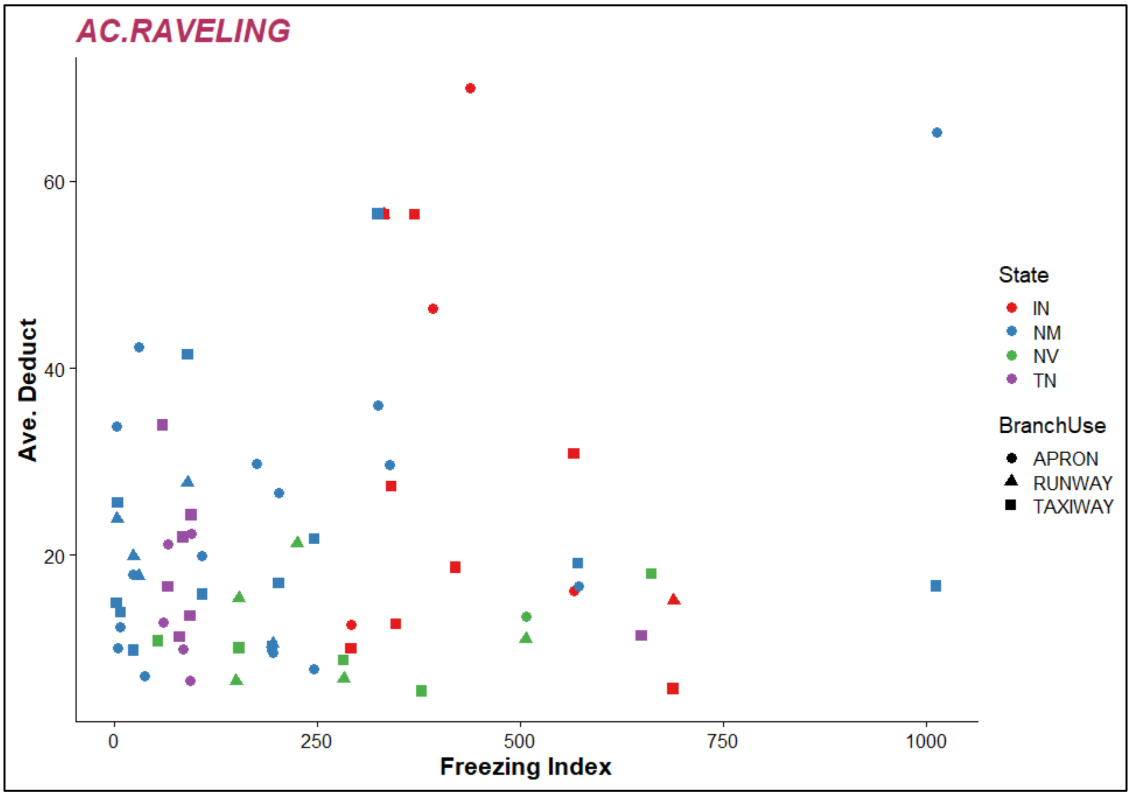
APPENDIX D

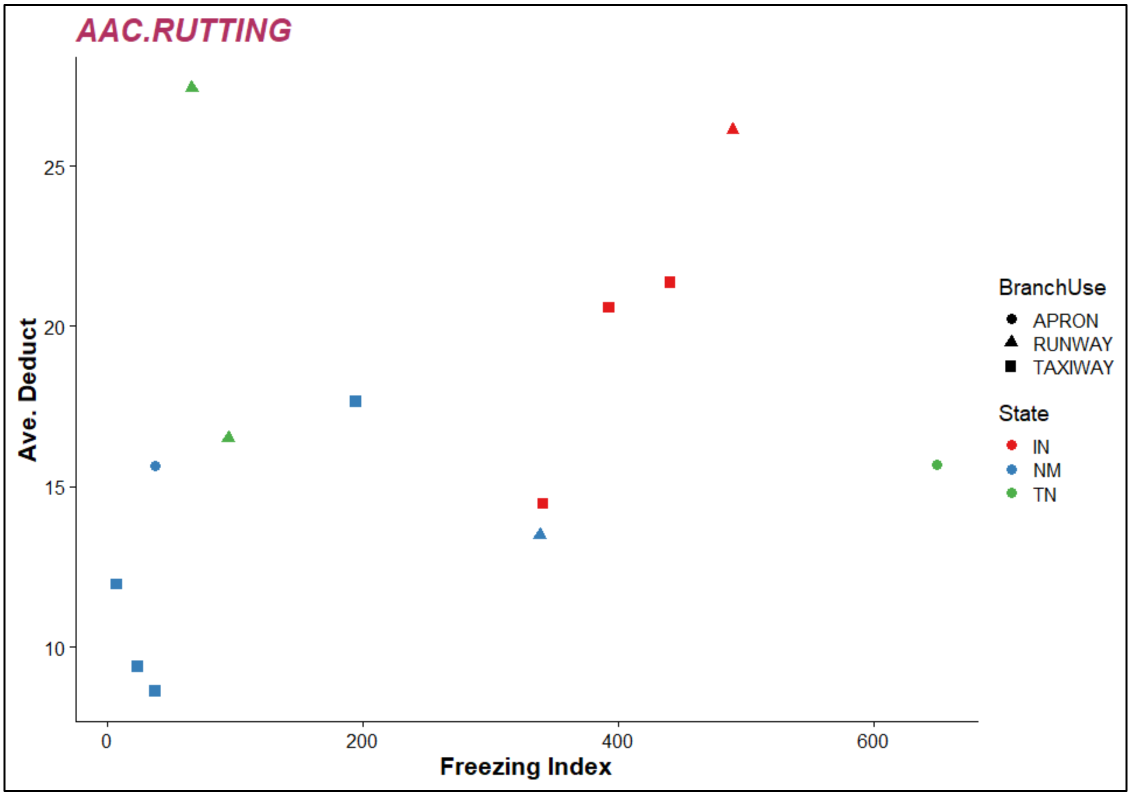
DEDUCT VALUE (DV) CORRELATION WITH FREEZING INDEX (FI)

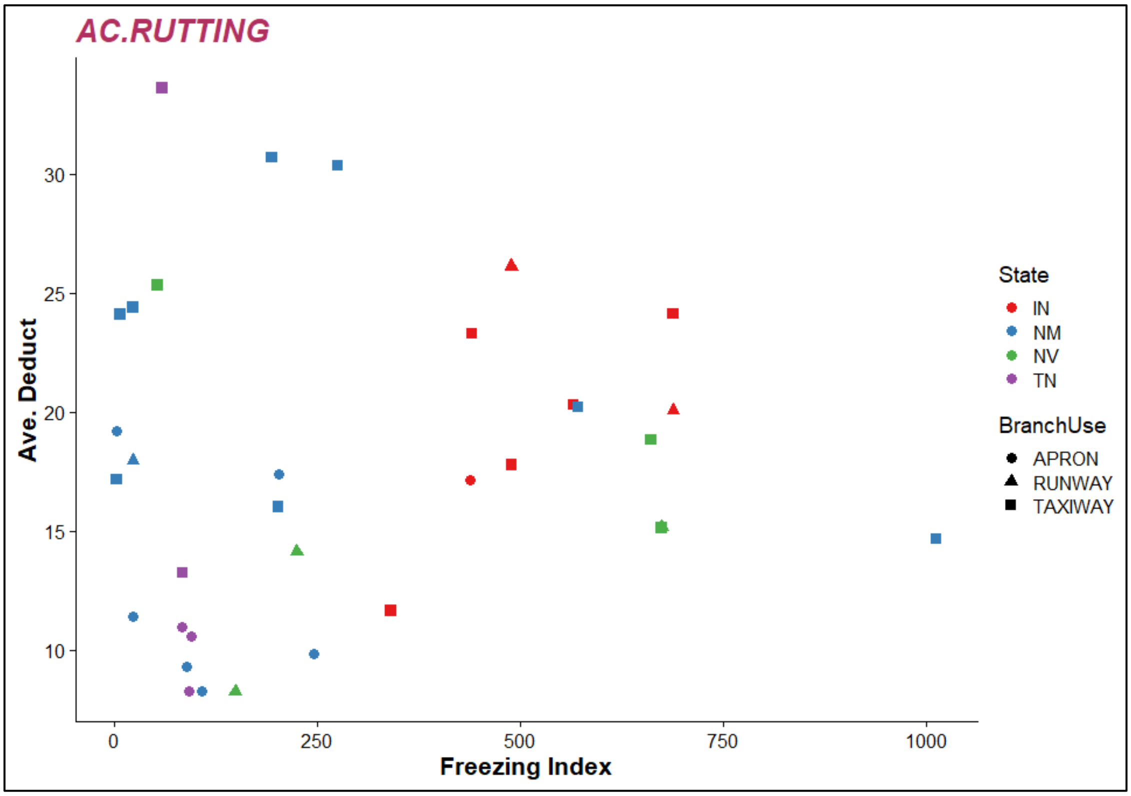

AAC.ALLIGATOR CR
Ave. Deduct
60
40
20
0
200
400
600
Freezing Index
State
IN
NM
NV
TN
BranchUse
APRON
RUNWAY
TAXIWAY

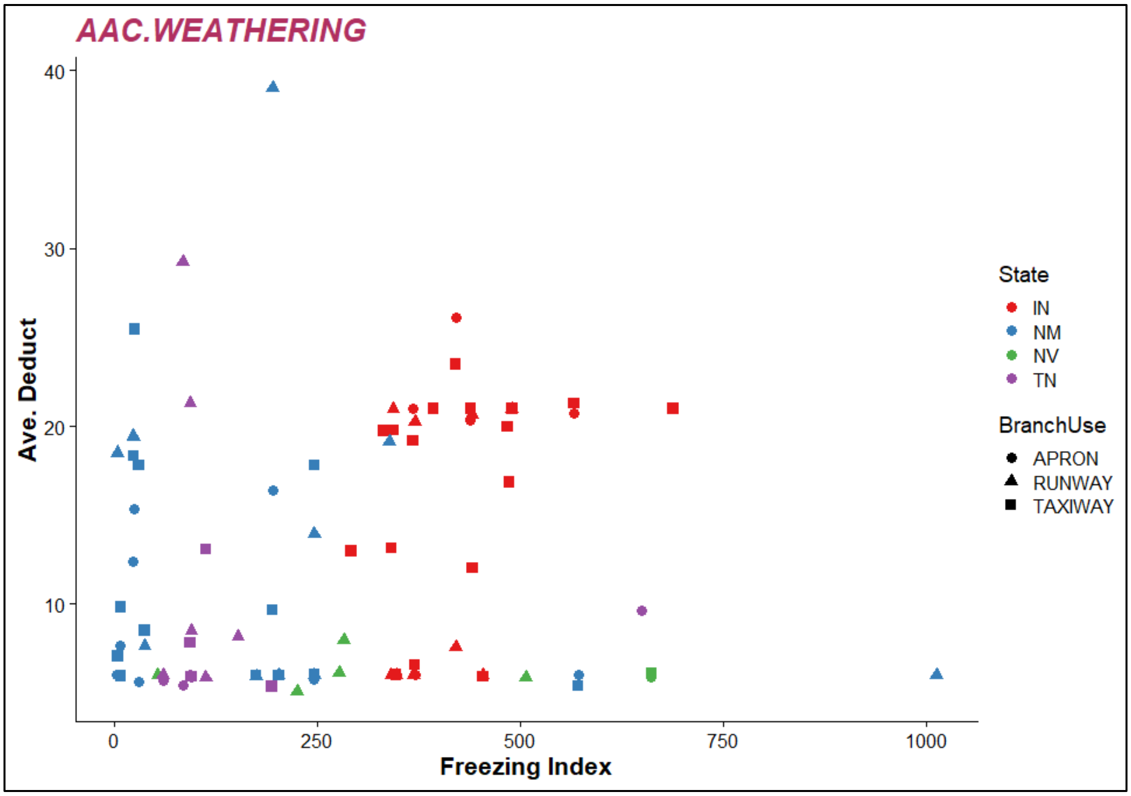

AC.ALLIGATOR CR
Ave. Deduct
60
40
20
0
250
500
750
1000
Freezing Index
State
IN
NM
NV
TN
BranchUse
APRON
RUNWAY
TAXIWAY

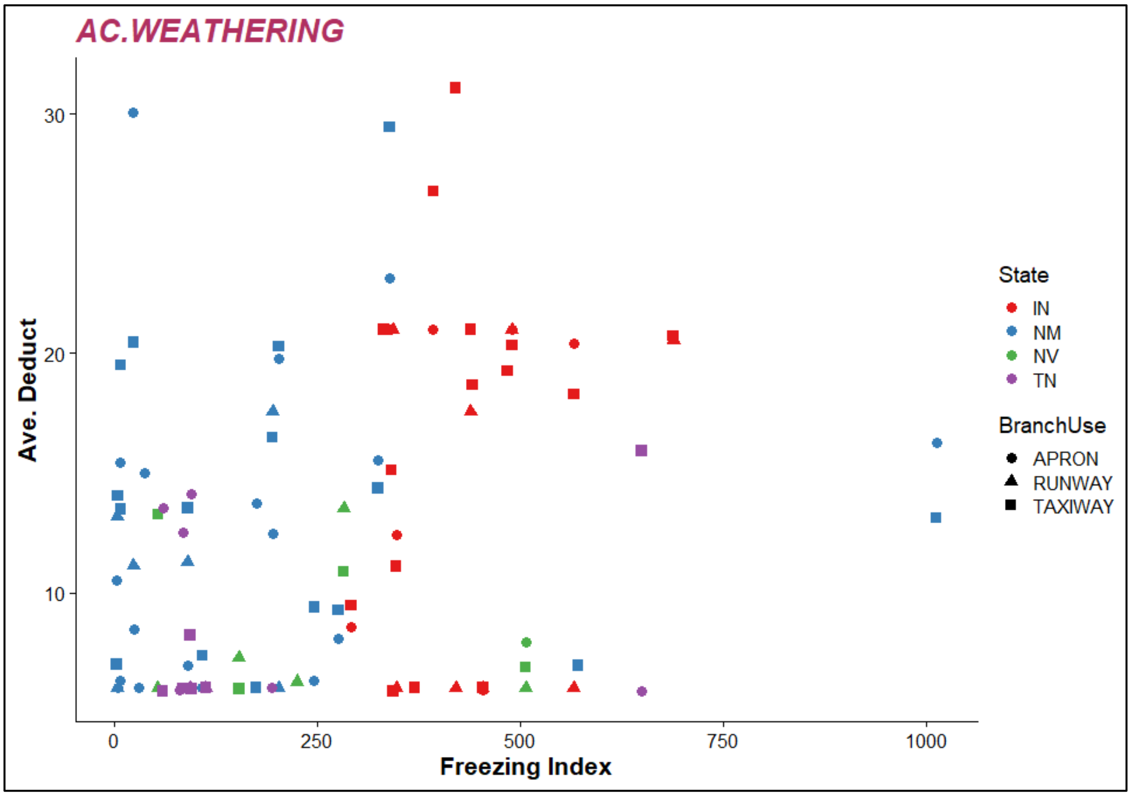

AAC.RAVELING
Ave. Deduct
50
40
30
20
10
0
200
400
600
Freezing Index
State
IN
NM
NV
TN
BranchUse
APRON
RUNWAY
TAXIWAY


AC.RAVELING
Ave. Deduct
60
40
20
0
250
500
750
1000
Freezing Index
State
IN
NM
NV
TN
BranchUse
APRON
RUNWAY
TAXIWAY


AAC.RUTTING
Ave. Deduct
25
20
15
10
0
200
400
600
Freezing Index
BranchUse
APRON
RUNWAY
TAXIWAY
State
IN
NM
TN


AC.RUTTING
Ave. Deduct
30
25
20
15
10
0
250
500
750
1000
Freezing Index
State
IN
NM
NV
TN
BranchUse
APRON
RUNWAY
TAXIWAY


AAC.WEATHERING
Ave. Deduct
40
30
20
10
0
250
500
750
1000
Freezing Index
State
IN
NM
NV
TN
BranchUse
APRON
RUNWAY
TAXIWAY


AC.WEATHERING
Ave. Deduct
30
20
10
0
250
500
750
1000
Freezing Index
State
IN
NM
NV
TN
BranchUse
APRON
RUNWAY
TAXIWAY