Innovative Approach to Airfield Pavement Inspections and Distress Identification at Oakland International Airport

Submitted: December 8, 2014

to the
9th International Conference on Managing Pavement Assets

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Word Count: 3831
Tables: 2
Figures: 7
Total word count: 6081
Abstract

Visual collection of surface distresses on airfield pavement in support of pavement management is becoming increasingly challenging for airports. Operational constraints limit access time for inspections on high priority pavements, and reductions in funding and operational staff resources lead to constraints in access to visually inspect pavements. Airports are increasingly relying on contractors and consultants to provide their own escorts, driving up the cost of Airport Pavement Management System (APMS) program.

The use of high speed imagery for airfield pavement management is not a new concept. It has historically been limited in its ability to provide accurate distress data used to determine the Pavement Condition Index (PCI) in accordance with Federal Aviation Administration (FAA) Advisory Circular 150/5380-6B. The limitations and challenges have ranged from poor image quality to difficulty referencing images to the pavement management segmentation and sample units.

This paper will review a case study with the most current technology completed at Oakland International Airport in California, USA that discusses an innovative approach to data collection, analyses and processing techniques using geospatial methods. This allowed the airport to benefit from highly specialized data collection equipment that generally is used to collect data for large roadway networks one lane wide, such as State highway networks, and report basic crack data summarized by milepost. Airfields require distress data at a more detailed level and also need the data to be presented across full pavement widths which can exceed ten times the width of a data collection pass in the case of runways.

The airport was able to realize the benefits of this approach by quick data collection that reduced the operational impact and necessary pavement closures; high quality 3-D imagery that is now maintained as a permanent record of condition and displayed and accessible on their in-house GIS (Port View); 100 percent distress coverage on key pavement features; and improved maintenance plans.
INTRODUCTION
An Airfield Pavement Management System (APMS) is a mandatory requirement of the Federal Aviation Administration (FAA) for airport projects funded with federal grant monies through the Airport 24 Improvement Program (AIP) and/or with revenue from the Passenger Facility Charges (PFC) 25 Program. As noted within the FAA’s Advisory Circular 150/5380-7B (1), an APMS is a set of defined procedures for collecting, analyzing, maintaining, and reporting pavement data. APMS assists airports in finding optimum strategies for maintaining pavements in a safe serviceable condition over a given period for the least cost.

An APMS requires an airport to assess the surface condition of their pavement through a visual inspection process. For airports completing a full update every three years, the surface condition is determined in accordance with FAA with Federal Aviation Administration (FAA) Advisory Circular 150/5380-6B to determine the Pavement Condition Index (PCI). Typically, PCI data is collected for a statistically representative sample set, often to achieve a 95% confidence rate (2) on each pavement branch (ie. Runway, Taxiway) at an airport, which generally results in a sample rate from 15% to 50% of the branch and an airport-wide average on the order of 25%.

The resultant data is used to generate PCI metrics for each pavement section, and further used to develop Capital Improvement Plans (CIP) for the pavement over a five to ten year planning horizon. Increasingly, the effort to collect this data, while important from a planning and AIP perspective, is operationally burdensome for airports who must provide staff for escort of the PCI crews in the airfield movement areas. Airports have been moving the resource burden for escort effort to the consultant. This, consequently, is driving up the cost of APMS for airports, and also, from a consultant perspective, is placing a less experienced escort on an active airfield leading to a less efficient process and potentially increasing the risk of incursions. In addition to the operational staffing burden, the closure time required for PCI inspections at many airports is a significant challenge. There is a need for the process to be less intrusive to the airport operation.

A potential solution to these challenges is the use of high speed data collection equipment that can take downward-facing images of the pavement and allow PCI surveys to be completed outside of the active airfield environment. High speed data collection is not new to the APMS platform. For example, images have been used to determine PCI by the Port Authority of New York and New Jersey at their airports since the early 2000’s. The technology has continued to improve over the last decade and a half, however, and that has brought forth the opportunity for optimized use of the image data outside of the traditional APMS platform.

The Port of Oakland (Port) completed an APMS project in 2014 at Oakland International Airport (OAK) that employed leading-edge high-speed data collection technology to collect pavement images on selected pavements in order to develop both a CIP as well as a robust preventive maintenance program. Rather than completing a separate inspection to determine maintenance needs as is common at many commercial airports, one data collection event was used to capture data for both programs. The Port significantly reduced the operational impact of data collection and in the process was able to establish a preventive maintenance program that they had previously had difficulty achieving with limited resources to perform a detailed maintenance inspection.

This paper provides a case study of the process implemented for the Port at OAK to enhance and expand the use of APMS data while minimizing the operational impact of the inspection program and the resultant benefits to the Port.
TECHNOLOGY REVIEW
High speed video technology generally collects downward facing image data in 1mm lines across a width of between 13 to 14 feet, or just wider than the vehicle itself. The lines are then processed into images (jpegs) roughly 26 feet long x 13.2 feet wide. The downward facing images are used to view the distresses. There has been a significant evolution of technology over the past 10 years. Within that time frame, the Laser Crack Measurement System (LCMS) has been developed by Pavemetrics. LCMS uses laser technology as shown in Figure 1 (3) and high definition cameras to collect 3D pavement imagery.

FIGURE 1: LCMS Laser scanning technology

The predecessor to LCMS is the Laser Road Imaging System (LRIS) by Pavemetrics, which provides only 2D imagery. Figures 2 and 3 provide the distinction between the two technologies, showing pavement distress at the same location using each technology. From a pavement rater perspective, the 3D imagery provides significantly improved clarity over the older technology allowing for much higher level of confidence in resultant Pavement Condition Index (PCI) ratings.

FIGURE 2: Traditional 2D imagery (LRIS)

FIGURE 3: High definition 3D imagery (LCMS)
The study investigated two critical issues:

1. **Context**: High speed imagery equipment was developed primarily as a roadway tool, and as such, is only able to view one 13 foot ‘pass’ of data collection at a time. Since airfield branches can be up to 200 feet wide, plus shoulders, it can take up to 20 passes of the equipment along the length of the runway to collect the full branch. When reviewing the resultant images, processed in a manner developed for roads, the context of the airfield is lost. For example, wheel-paths of aircraft simply do not match up with cars and trucks. To make the most out of this type of data collection at an airfield, an alternative ‘airfield-friendly’ approach is needed.

2. **Automation**: With the 3D LCMS imagery clearly showing the type, severity and extent of distresses, there is a need to improve distress automation for airfields. Since the full pavement surface is collected during the passes of the vehicle, it is possible to extract distress for 100% of the surface. This process, however, is not economical without automating some of the distress interpretation.

**PORT OF OAKLAND BACKGROUND**

Oakland International Airport was first opened in 1927 and is located on approximately 2,600 acres of land. OAK currently consists of two airfields – North Field and South Field, as shown on the annotated Airport Diagram in Figure 4.

**FIGURE 4: Oakland Airport Diagram**
Both fields include landside and airside pavements, and the focus of the study included only airside pavements, which are pavements inside the Air Operations Area (AOA) that are inaccessible to the general public.

The original airfield was located at North Field, which currently serves corporate and general aviation, as well as small air cargo operations and commercial airlines as needed. North Field includes three runways (15-33, 28R-10L, and 28L-10R) with lengths ranging from 3,372 feet to 6,213 feet, and associated taxiways, aprons, and hangars.

South Field, which opened in 1962, primarily serves commercial passenger service and air cargo operations and has one 10,000-foot-long runway (12-30), associated taxiways, aprons, cargo buildings, and terminal buildings. The Airport’s commercial passenger terminals, Terminals 1 and 2, have a total of 29 gates. In 2013, OAK served 9.74 million passengers, as compared to its 2007 peak of 14.6 million passengers. Total air cargo in 2013, including freight and mail, was 555,586 tons.

Overall, the Airport’s airside pavements consist by area of 39% taxiways, 34% aprons, 25% runways, and 2% service roadways. All of the Airport’s runways are constructed of asphalt concrete (AC) pavement, as are all of the South Field taxiways and most of the North Field taxiways. Parking aprons at the Airport primarily are constructed of Portland cement concrete (PCC) pavements. North Field pavements consist of 71% AC and 29% PCC, while South Field pavements consist of 79% AC and 21% PCC.

The majority of the South Field pavements have been reconstructed over the past 10 years, with the notable exception of Runway 12-30, which last experienced major construction in 2001. Conversely, the vast majority of North Field pavements last experienced major reconstruction prior to 2004. The PCI weighted averages for North Field and South Field are 82 and 92, respectively, with an overall PCI weighted average for the Airport’s airfield pavements of 88.

Because the Airport has only one main runway (Runway 12-30) for commercial and cargo operations, it is quite heavily used and, as a result, has very limited opportunities for inspections and repairs. The Airport allows only one scheduled time per week to perform inspections, maintenance, and repairs for this runway: Monday mornings from 1:30 am – 6:00 am. Heavily used taxiways are also subject to the same or similar time constraints. Work in this timeframe, under night time conditions with poor lighting and oftentimes poor weather conditions, negatively affects the quality, cost and productivity of all work on the runway and associated taxiways, including pavement inspections.

As the airfield pavements have a relatively good overall PCI, the Airport has been turning its focus toward preventative maintenance to maximize pavement life. The Airport’s past experiences with APMSs have yielded good information that was not easily visualized or accessible and, therefore, not well understood or used. This current APMS was aimed at addressing these issues by making the PCI and crack mapping data accessible to Port staff by way of the Port’s existing GIS program, Port View. This program allows Port staff to access color-coded PCI maps, crack maps, and 10-year CIPs of airfield pavements at their individual workstations and create work plans to aid in identifying pavement distress and assigning maintenance activities.

**INNOVATIVE APPROACH**

The need for OAK to collect pavement management data quickly, working within the constraints of the heavy use in the South Field, coupled with the desire to focus on preventive maintenance, provided an opportunity for the Airport to utilize an innovative approach to pavement management.
The Airport opted to utilize high speed data collection equipment, specifically LCMS, on select pavement branches to minimize the operational impact and also to use pavement distress data determined via the imagery to develop and assess maintenance needs for its preventive maintenance program. The use of LCMS on Runway 12-30, in particular, reduced the required field time from approximately 12 hours, to less than 3 resulting in a 100% coverage distress and PCI map rather than a 20% sample of the condition.

For example, traditional manual inspections in accordance with FAA 150/5380-6B may be planned to achieve a 95% confidence level, statistically. Each pavement branch is divided into homogeneous sections, which are then further broken down into 5,000 square feet (SF), (±1,500 SF) sample units (in the case of flexible pavement). A section may have 20 sample units, but only 5 would be surveyed. The resultant PCI is considered representative of the section, and further sample units would really only provide diminishing returns as far as improving the PCI value. However, when determining maintenance needs, the distress for these 5 samples, for example, will be extrapolated to the remaining 15 and used to estimate maintenance quantities such as crack seal. This is generally inaccurate and also does not provide Airport maintenance with any direction as to the location of the maintenance requirements. A map of the cracks, conversely, shows exactly where the cracks are that need sealing, and can provide very accurate material quantities to estimate material costs, labor requirements, and necessary closure times to perform the maintenance. Figure 5 provides a map of the South Field where the dark green rectangles indicate sample units that were surveyed and light green are samples not surveyed.

FIGURE 5: Sample units surveyed in South Field (Dark Green)
As can be seen in this figure, the full extent of the main runway, Runway 12-30, (not including shoulders) was mapped as compared to the parallel taxiway, Taxiway W, that had only a statistical survey performed.

To handle the critical issues previously identified in the ‘Technology Review’ section, innovative thinking was needed to most effectively apply the LCMS technology to the airfield environment and this is discussed in the following sections.

Image Context
Data collection was completed on a branch in full-length straight passes of the LCMS along the selected pavement branch. The trace plots representing the geospatial co-ordinates of the centerline of data collection were reviewed to ensure no gaps between data collection passes existed. This was done “on the fly” by the data collection team. Rather than using the data collection vendor’s road workstation software, or MicroPAVER’s imageinspector to view the data, an innovative process was developed to view all of the images within ArcGIS, as one would view aerial photography. A constraint with the data that was received, is the lack of GPS location co-ordinates tagged to the images if using them outside of the vendor software.

By utilizing the dimensions of the images, the centerline trace plots, as well as the naming convention (images were collected and numbered in sequence), a simple computer program was written to extract the co-ordinates of the vertices from the trace plot shape file and construct special files that assigned the relative position of each image. The software allowed for this previously cumbersome and time-consuming process to be automated. The results are shown in Figure 6.

![Figure 6: Full context (width) of runway images in ArcMap](image-url)
Considering that image dimensions are generally 26.4 feet long by 13.2 feet wide, a 10,000-foot-long runway would have approximately 380 images per pass (and over 4,500 total images for all passes), automation was necessary. A separate geodatabase was then created for each branch that was collected. Within each geodatabase, a separate mosaic dataset was created for each data collection pass. This allowed passes to be turned on / off, and for the pavement rater to determine which were displayed on top (in the case of overlapping images). By creating a mosaic data set for each pass, all images within the pass were treated as a single object, rather than the 380 images per pass as separate objects. This made the dataset much more manageable. As shown in Figure 6, the full width of the runway data collection can be viewed in ArcMap, and the image can be magnified by the rater to clearly show distresses as seen in Figure 7.

![Image of ArcMap showing pavement distress](image-url)

**FIGURE 7: Zoom in to review pavement distress**

Figure 7 shows the slight error in alignment of passes where passes have been jointed at the centerline light, there is a slight (approximately one and a half inch) shift between the passes. Once the images were within ArcMap, the pavement distresses were easily mapped as lines and polygons to develop a geodatabase of distresses that were then spatially assigned to the appropriate sample unit and used to create a MS Access database for upload into the MicroPAVER pavement management database. The Access database was simply formatted in accordance with the MicroPAVER video inspection import data format (4). The resultant product included both Pavement Condition Index (PCI) in MicroPAVER, and distress maps in ArcMap. The Port was also able to take the resultant imagery within the ArcMap format, and
integrate it within its web-based GIS system, PortView. This allows Port staff to view clear images of the pavement condition with ease, all while sitting at their workstation.

**Automation**
The effort to assess the distresses on the pavement using ArcMap is quicker than the time it takes to do this in the field. For example, if a survey team of two can collect distress on eight (8) sample units within an hour, a single rater can complete the same effort in approximately two-thirds the time – but half the manpower. If the intent is to do 100% survey coverage for mapping of cracks, then the total number of samples to survey will be much higher (100% rather than 20%) and therefore the complete labor cost will generally exceed the traditional on foot approach. There is an additional cost for the high speed data collection itself, making this approach overall more costly, but with a more enhanced end-product.

To bring the costs more in-line, automating the distress identification and classification was considered. There has been extensive work completed on this in the roadway industry. Airfield distress automation, however, has not been advanced. Since many of the roadway automation methods rely on ‘binning’ the data into wheel-paths, to identify fatigue cracking, the issue of context on the airfield will impact the ability to use existing automation. Applying automation was outside of the scope for the OAK project; however, some research and development efforts were completed to assess the potential for automation. A prototype ‘Pavement Distress Classification’ model was developed and used on the imagery to determine the potential for its future use. Only a limited data set was run through the models, and this included flexible pavement only. Increasing the size of the data set would benefit the models. As shown in Table 1, the occurrence of some distresses was too infrequent to develop meaningful statistical outcomes. Table 2 provides the resultant Area Under the Curve (AUC) measure of the results. The AUC measure ranges from 0.5 to 1, where 0.5 implies that the model’s ability is equivalent to random guessing and 1 implies that the model is perfect.

**TABLE 1: Comparison of Distress Counts by File**

<table>
<thead>
<tr>
<th>Distress</th>
<th>Runway 12-30 Pass 1</th>
<th>Runway 12-30 Pass 2</th>
<th>Runway 15-33 Pass 1</th>
<th>Runway 15-33 Pass 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear / Transverse Cracking</td>
<td>291</td>
<td>260</td>
<td>121</td>
<td>43</td>
</tr>
<tr>
<td>Patching</td>
<td>111</td>
<td>39</td>
<td>80</td>
<td>81</td>
</tr>
<tr>
<td>Alligator Cracking</td>
<td>6</td>
<td>16</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>Weathering</td>
<td>1</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Block Cracking</td>
<td>0</td>
<td>0</td>
<td>18</td>
<td>29</td>
</tr>
<tr>
<td>Total Distress Samples</td>
<td>409</td>
<td>320</td>
<td>230</td>
<td>165</td>
</tr>
<tr>
<td>Total Images</td>
<td>396</td>
<td>396</td>
<td>127</td>
<td>127</td>
</tr>
</tbody>
</table>

**TABLE 2: Model Accuracy**

<table>
<thead>
<tr>
<th>Distress</th>
<th>Model AUC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear / Transverse Cracking</td>
<td>0.96</td>
</tr>
<tr>
<td>Patching</td>
<td>0.91</td>
</tr>
<tr>
<td>Alligator Cracking</td>
<td>0.67</td>
</tr>
<tr>
<td>Weathering</td>
<td>0.97</td>
</tr>
<tr>
<td>Block Cracking</td>
<td>0.78</td>
</tr>
</tbody>
</table>
As shown in Table 2, there exists good potential for automating the airfield flexible pavement distresses and that with more data the models can be better calibrated to achieve higher AUC’s.

The potential move to automation of the distress interpretation will allow airports to develop crack maps from LCMS data in a more cost effective manner, effectively closing the gap between the costs for traditional statistical based data collection methods.

**SUMMARY**

High speed video data collection, specifically LCMS, was successfully used at Oakland International Airport as part of its APMS program. Approximately thirty percent of the total pavement area was surveyed in 2014 using this method. The resultant imagery was packaged as a viewable ArcGIS map document and used to identify pavement distresses to determine PCI, comply with the requirements of FAA for AIP funding, and prepare preventive maintenance plans.

Key technological improvements to the state of airfield inspections using LCMS for this project included:

- “On the fly” identification of scanned areas and adjustments to ensure 100% coverage
- Automated image stitching and coordinate identification
- Further development of automated distress identification

The key benefits realized by the Port through using this innovative approach included:

- Minimum disruptions to Airport Operations (two hours per runway). Based on the allowable weekly closure window for Runway 12-30 specifically, this resulted in a time savings of two to five weeks depending on data collection crew size and percent of survey coverage.
- 100% coverage of the survey area resulting in accurate PCI results and the ability to review PCI at the sample unit level to look for variations.
- Detailed crack maps used to develop preventive maintenance plans.
- Full survey coverage with crack mapping that can be used for project-level designs on upcoming projects.
- Increased geospatial accuracy of distress locations to support Port staff in identifying and locating concerns as they may relate to Part 139 inspections, and also to use in future inspections.
- Baseline condition of the pavement as a clear image that can be used to observe and track distress deterioration, especially on the critical main runway.
- Image accessibility to all Port staff from within the Port’s PortView web-based GIS application.

The LCMS in general provided an enhanced product to the Port. The enhancements had a higher cost than traditional methods. If these costs can be reduced due to improvements in automation of distress classification, then the LCMS package could represent the new ‘traditional’ method for APMS.
Future developments that could make LCMS more of a mainstream method, and possibly replace manual inspections, include:

- Wider span of lasers, resulting in more efficient and complete coverage in the field.
- Improvement in automation of image stitching, in particular for non-linear pavement branches.
- Automation of pavement distress identification, in which accuracy will improve as more data become available.
- Lower relative cost of LCMS versus manual inspections.
References