AIRPORT SURFACE SURVEILLANCE DATA IMPROVES PAVEMENT MANAGEMENT EFFICIENCY AND COST EFFECTIVENESS

By:
B. Levy, M. Carpenter, S. DeHart and T. Nolan
Saab Sensis Corporation
85 Collamer Crossings, E. Syracuse, NY 13057
USA
blevy@saabsensis.com
(315) 234-7920

R. Boudreau
Boudreau Engineering, Inc.
5392 Blue Iris Court, Norcross, GA 30092
USA
rlboudreau@comcast.net
(404) 388-1137

Q. Watkins
Michael Baker Engineering, Inc.
3595 Engineering Drive, Norcross, GA 30092
USA

PRESENTED FOR THE
2014 FAA WORLDWIDE AIRPORT TECHNOLOGY TRANSFER CONFERENCE
Galloway, New Jersey, USA

August 2014

ABSTRACT

An airport pavement management system is the basis for planning maintenance, rehabilitation, or reconstruction activities for airside pavement infrastructure. Airport authority engineers use counts of arrival and departure operations to make initial assumptions of how these arriving or departing aircraft taxi between runways and gates as a gross estimate of the true stress allocation over the pavement network. The quality of these estimates can be improved with data that measures the *actual* traffic patterns and aircraft characteristics, providing better pavement lifetime assessments and reducing maintenance and refurbishment costs. This approach is in the early stages of development at Hartsfield-Jackson Atlanta International (ATL) Airport. While the test and inspection tools are essential to the accurate assessment of the pavement condition index (PCI), unnecessary and laborious inspection of large regions of pavement could be avoided through the use of airport-wide traffic data to guide the program and set priorities for inspection.

A unified analysis capability incorporating databases, simulation, and algorithms has been created to measure and characterize actual aircraft surface traffic patterns based on surveillance data and project alternatives using simulation. This paper applies that capability to improve upon the accuracy of the knowledge of pavement usage.

The surveillance data measure aircraft position within 30 feet and timing to the second. While less accurate in position estimation than a hand-held GPS device, the airport surveillance data provide a complete 'view' of all aircraft traffic on and around the airport. The airport surveillance system also provides extensive coverage in time (e.g., years of data) and all aircraft characteristics (e.g., size, weight, type, and direction of travel) needed to assess long-time, systemic pavement condition and wear.

Aircraft position data from the airport surveillance system are linked to flight information, including arrival/departure status, aircraft type, and weight. The database can provide aircraft loading at the pavement slab and segment levels. The accuracy and comprehensive data content improve the accuracy of pavement stress and the calculation of cumulative damage. Having more accurate and comprehensive pavement loading data provides the opportunity to improve engineering evaluation and analysis reliability.

Pavement inspections, testing, and maintenance activities impede aircraft traffic flow, causing taxi delays which directly result in increased operational costs. Surface surveillance data can be used to determine pavement segment closure timing with reduced operations impact. Surveillance data can also be used to develop and simulate taxi routing alternatives, reducing the taxi delay and associated operations costs. Surface operations simulations can be developed to allow airport planners to rapidly assess the economic impact of closing a specific pavement segment for maintenance, rehabilitation, or reconstruction.

INTRODUCTION

It has been noted that large-scale, long-duration, widespread airport surface surveillance data could be used to: improve pavement management; save costs of unneeded testing and replacement; and, quantify the benefit to the users of the airport [1]. With the advent and availability of large volumes of airport surface surveillance data, it is now possible to utilize these data in a Geographic Information System (GIS). Surface surveillance data processed in a GIS can answer questions about the condition of airport pavement and airport management:

- Which pavement segments carry the highest traffic volume and when does it occur (e.g., peak hour, peak day)?
- Do these high-volume segments create delay situations, which can increase load and stress on pavement?
- Is it useful to have an airport-wide "heat map" that shows traffic volumes (e.g., Very High [red], High [orange], Moderate [yellow], Low [blue], and Very Low [green])?
- Can knowledge of aircraft traffic mix and frequency be utilized to enhance the reliability of structural performance models?
- Can the traffic level be combined with pavement attributes (e.g., age, concrete thickness, condition score) to isolate areas which could be compromised structurally?
- Can the cost and benefit to airport 'customers' (e.g., airlines, passengers) due to construction delays and improvement be estimated as well as the better-known cost of the construction program itself?
- Can the alternatives for impact and delay mitigation during construction (e.g., gate-holding, schedule-thinning, traffic management) be evaluated with simulation?
- Can identification of high-traffic volume regions be used to help guide field inspection planning?

This paper represents examples of using large data sets and sophisticated software, which provide new capabilities for airport management, analysis, and visualization. More specifically, this paper presents the analysis based on a day's worth of airport surface surveillance data at ATL Airport and utilizes a shape file that describes the boundaries of *individual* slabs of concrete. This example illustrates how these data sets may be generated in order to facilitate querying, visualization, and modeling in a GIS framework. With trajectory reconstruction of surveillance data, it is possible to determine the surface trace of aircraft wheels given information on the aircraft and its transponder location. A conceptual plan describing how airport managers may evaluate the impact of construction and longer-term growth on their airport operations through the use of a medium-fidelity simulation framework is also provided.

BACKGROUND

The US Federal Aviation Administration (FAA) Office of Airports sets policy and provides guidance and funds (i.e., Airport Improvements Program – AIP) for the safe and efficient maintenance and upgrades to the nation's airports. Guidance for pavement assessment and the disbursal of AIP funds is undertaken by the Airports Office [2]. The screening and assessment of airport pavement condition is prescribed by the FAA Advisory Circular AC-150/5380-5B [2], which recommends using the ASTM D 5340, *Standard Test Method for Airport Pavement Condition Index Surveys* [3] for performing, calculating, and reporting the PCI. The PCI is a dimensionless quantity that ranges from 0 ("worst possible condition") to 100 ("best possible condition"). A PCI survey must be completed at least once every three years if the ASTM methodology is followed; otherwise, the survey must be conducted at least once per year [2]. A yearly PCI survey could represent a large expense to survey the surface of an entire airport.

A condition of receipt of AIP funds is the existence of an airport pavement management plan (APMP), which prescribes the tracking and cause of pavement deterioration [4]. The APMP must contain an inventory of the location of pavement and associated characteristics (e.g., type, dimension, year built) [4]. Airport surface surveillance and aircraft weight data could augment the APMP and improve systemic pavement condition tracking. Across many airports, the PCI methodology standardizes assessment for disbursal of FAA AIP funds. At the airport engineering design level, however, there is an opportunity to maximize the use of AIP funds by adding aircraft surveillance data and characteristics databases to the existing pavement condition assessment tools used by engineers. Note, that while it is acknowledged that the field inspection of pavement an essential, time-consuming task, we do not suggest that this surveillance-based approach as a replacement but as a high-level screening tool to plan and guide inspection.

METHODOLOGY

Field evaluations of pavement conditions may be performed with a variety of test and inspection techniques (e.g., falling weight deflectometer, visual inspection, coring) [5]. The result of these data collection efforts is a PCI, which is used to create an airport-wide assessment of pavement conditions and to guide pavement replacement and repair priorities. Figure 1 shows the PCI map for ATL Airport, as of 2010 [6]. While the test and inspection tools are essential to the accurate assessment of the functional and structural condition of pavement, unnecessary and laborious inspection of large regions of pavement could be avoided through the use of airport-wide traffic data to guide and set priorities for inspection.

Figure 1. Pavement PCI Map at ATL (Draft), 2010.

Widespread availability of high-quality airport surface surveillance data allows for the specific measurement of traffic impact on the airport surface at many large US Airports (Figure 2). Most major US Airports are equipped with the Advanced Surface Detection Equipment-Model X (ASDE-X) surveillance system. The FAA plans the deployment of the second phase of airport surveillance systems (Airport Surface Surveillance Capability [ASSC]) at nine subsidiary US airports. Additionally, some airports are equipped with 'stand-alone' multilateration (MLAT) systems which provide complete surveillance coverage across the ramp areas and the runway and taxiway network. SSC has years of airport surveillance data processed in flight-specific data format for many airports, which can be used for pavement assessment and air traffic simulation.

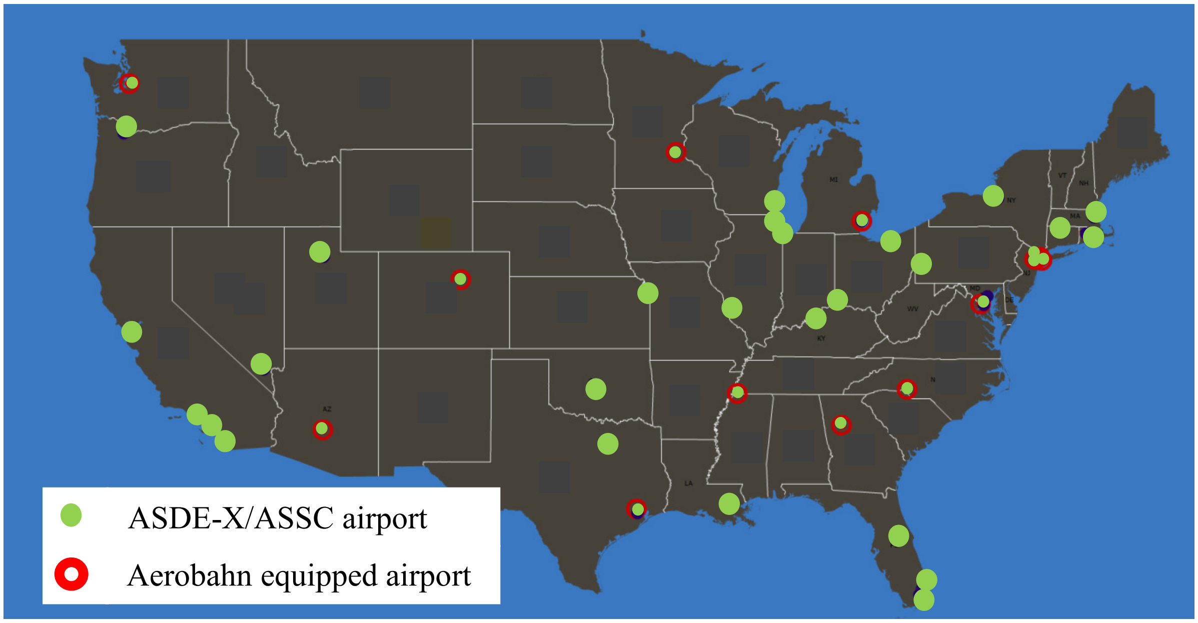

Figure 2. Location of ASDE-X and MLAT Systems at US Airports.

This paper demonstrates how a traffic database at ATL Airport may be constructed from airport surveillance data as an example of new analytical capabilities. SSC will further show that the individual aircraft tracks and wheel-traces can be plotted at the spatial scale of a pavement slab. This work will enable pavement engineers and airport authorities to provide airport-wide screening of traffic use with aircraft-specific characteristics (e.g., weight, wheel geometry).

A hierarchical approach is used for delineating areas for pavement engineering by dividing the pavement surface into small, manageable areas. The hierarchy conforms to the requirements of MicroPAVER [7], pavement management software implemented at ATL Airport in 2001. The following terminology is provided for subsequent reference:

Network - The entire airside pavement surface network at ATL Airport. This work has been limited to the concrete pavements, and does not include asphalt shoulders or service vehicle access roads.

Branch - A pavement feature with a uniquely assigned name/designation that is an identifiable part of the airfield (i.e., Runway 9L-27R, Taxiway B11, Taxiway N00, Ramp2) [3].

Section (Segment) - A portion of a Branch with common traffic volume and pavement construction history –thickness, materials, date, and maintenance history.

Sample Unit - Manageable inspection areas consisting of roughly 20 slabs of 25-foot plan dimensions.

Slab - An individual slab, and smallest polygon contained within ArcGIS® [8].

The use of surveillance and aircraft property data for pavement assessment with reference to slab-level and sample-level spatial elements are detailed in the remainder of the paper.

RESULTS

Data Definition and Collection

The following analysis and results are based on one day of airport surface traffic at ATL Airport on August 9, 2012 universal coordinate time (UTC), for which there were 2428 operations (arrivals and departures); a subset of the total daily operations of this data set is considered in the following exposition. The date of operations (8/9/12) is solely presented as illustration. The SSC data repository for ATL Airport extends from July 30, 2010 until current and is managed as a 'flight object'. Flight object information includes all relevant metrics and transient properties of a flight (Table 1).

Table 1.
Flight Object Fields and Selected Data Elements.

Field	Selected Data Elements
Operations	Time, x, y, z, ground speed
Schedule/flight plan	Scheduled On, Off, In, Out, first departure fix, first arrival fix, origin, destination
Aircraft characteristics	Call sign, mode S code, model, registration, maximum take-off-weight, number of seats, maximum landing weight
OOOI events and surface holds	On, Off, In, Out; location, duration, identity of aircraft surface holding
Weather (METAR)	Temperature, wind speed, wind direction
Departure queue	Entry and exit time, identity

A subset of the day's operations is shown on Figure 3 as flight position data (e.g., x, y) referenced to the airport surveillance system center (red traces transiting runway 9R/27L and Taxiway Romeo). The green polygons are the pavement slabs whose coordinates have been transformed from State Plane Coordinates to an East-North-Up map reference frame as x,y locations (m) with respect to the surveillance system center. The remaining material shows how a subset of the data and specific pavement region can be inspected for traffic properties inside the magenta-colored rectangle of Figure 3.

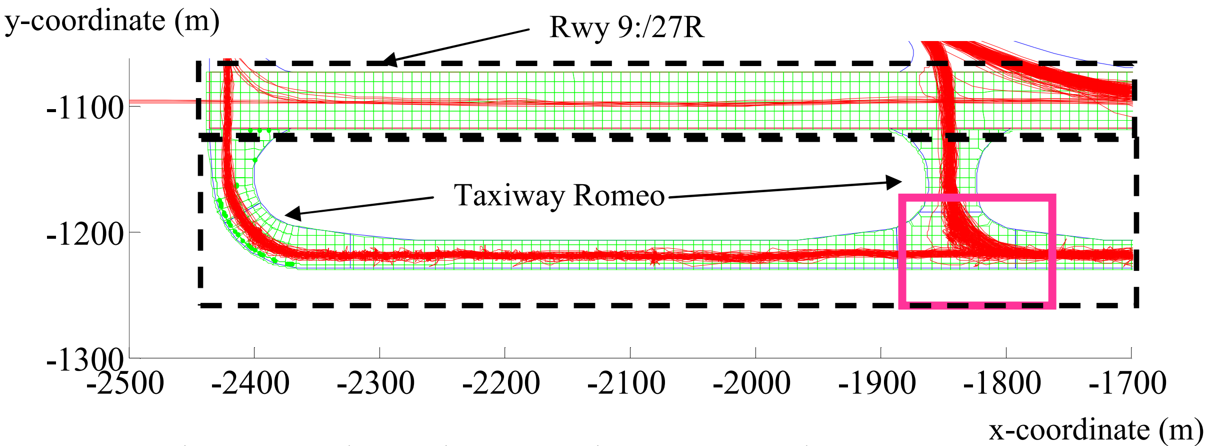

Figure 3. Track Locations on Taxiway Romeo and Runway 9R

Beginning with the flights that transited the pavement slabs on Taxiway Romeo within the magenta-colored rectangle of Figure 3, the pavement slabs are shown on Figure 4; coloring of regions in Figure 4 is provided for visual differentiation of pavement sections. **Figure 4**Aircraft wheel geometry can be used with trajectory position data to indicate which slabs are impacted and how many passes are needed to ensure coverage across all slabs. Again, the individual aircraft trajectories are shown with red traces. Positions where the aircraft held for some period of time are shown with black dots. The holding locations are where the aircraft imposed a static load on the pavement In Figure 4, the flights depicted are arrivals; no departures transited this region during the time period that encompasses this data set. Slabs are approximately 8 m x 8 m. Sample regions are color-coded (e.g., Sample R00-02-116 and its slabs appear with red borders).

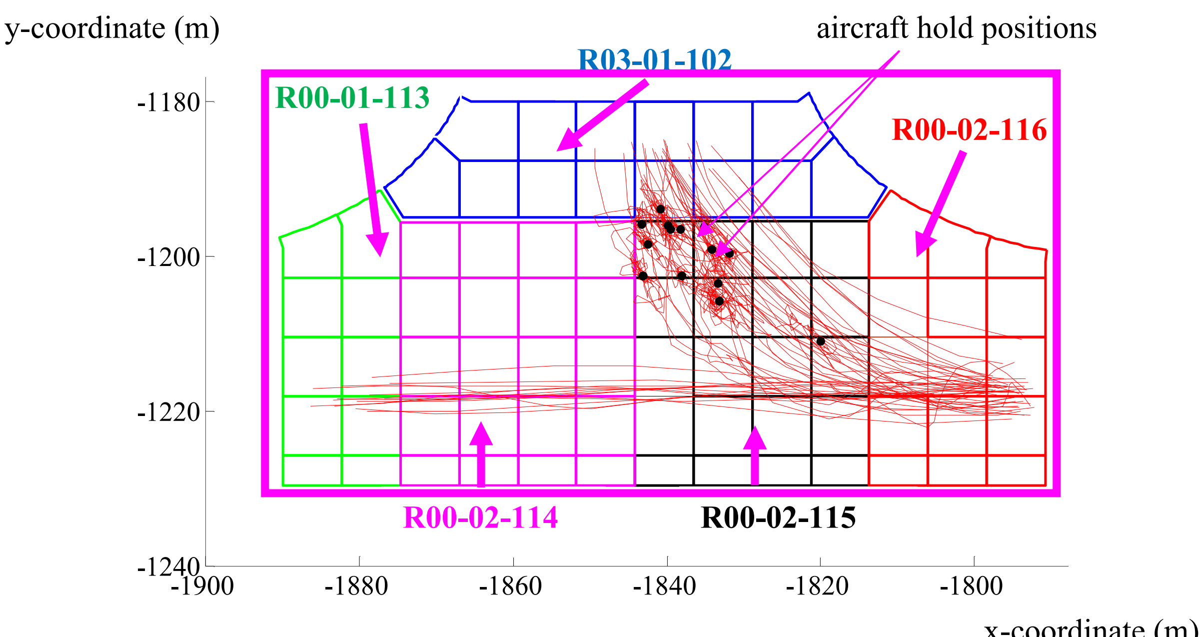

Figure 4. Section of Taxiway Romeo with Aircraft Traffic.

For each aircraft surveillance trace shown in Figure 4, it is possible to map the aircraft wheels as the aircraft passed across the pavement surface. In one example (Figure 5), the trace of an arriving B737-76N (registration N273AT) is shown. The trajectory trace and positions are shown on Figure 5 as a magenta-colored line and circles. Given information on the properties of the B737-76N and an assumption of the placement of the transponder (e.g., 35.8 m wingspan, 33.6 m overall length, transponder is 20% of aircraft length back from the nose), the location of the center-wheel and main landing-gear wheels on Figure 5 is estimated (blue trace and red traces, respectively). The individual pavement slabs across which the wheel positions transited are shown with black borders. This information shows that aircraft properties, trajectory data, and trajectory reconstruction can be used to augment structural deterioration models and perhaps the PCI evaluation methodology.

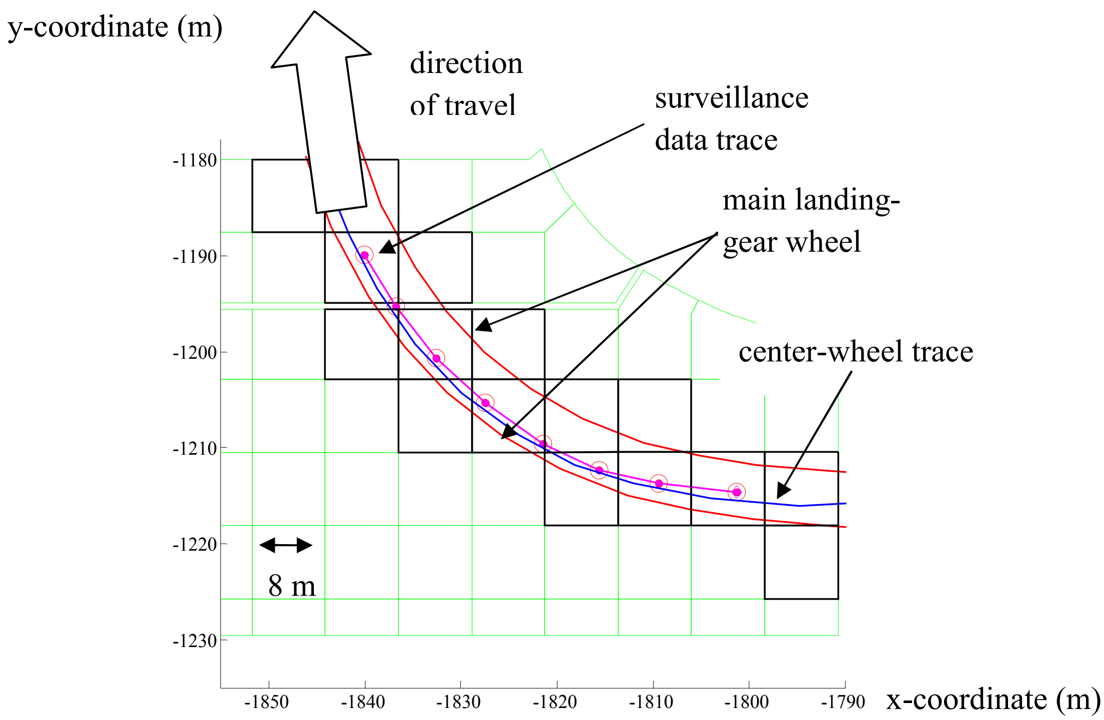

Figure 5. Wheel Trace on Pavement for B737-76N.

Data Reporting

The preceding subsection discussed the use of airport surface surveillance data for traffic pattern definition. This subsection presents the database construction in terms of its tables and views. For reference, a database 'view' is "…the result set of a stored query on the data, which the database users can query ... This pre-established query command is kept in the database dictionary. … a view .. is a virtual table computed or collated dynamically from data in the database when access to that view is requested."[9] We present the underlying tables first and then a possible database 'view' in order to organize and present the database architecture.

Properties of the flights that transited pavement samples R00-02-116, R00-02-115, and R03-01-102 form the basis for the database tables and 'views' that are created for ATL Airport using data from August 9, 2012. Referring to Table 2, the database table contains a unique identifier (e.g., flight id), which is composed of the call sign, an internal flight object integer, and the operations date (YYYYMMDDTHHMMSS format) string (i.e., landing time for arrival, take-off-time for departure). In Table 2, Table 3, and Table 4, the components of the flight id are denoted in bold-face font (i.e., call sign), plain-text (i.e., flight object integer), and in *italics* (i.e., operations date and time). The flight id forms the link between the flight database table and pavement region database table. The remaining columns in Table 2 depict the properties for a selection of flights on August 9, 2012, and include the call sign, tail number, mode S code, and maximum number of seats and take-off and landing weights.

Table 2.
Properties of the Flight Database.

id		aircraft		day of week	call sign	tail #	mode S code	maximum		
id	flight	type	dir.					seats	take-off wgt (kg)	landing wgt (kg)
1	**DAL2337**49080722 *20120809T000024*	DC-9-51	Arr	Thu	DAL2337	N766NC	11163905	139	54,885	49895
2	**DAL562**49081776 *20120809T000029*	MD-88	Arr	Thu	DAL562	N926DL	11326666	172	67,812	63276

Table 3 provides the information for flights in Table 2 that moved across the slabs of pavement R00-02-116, R00-02-115, and R03-01-102. Note that the first column in Table 3 contains the common flight id which allows the bridging and querying of the database to form a 'view' of the desired data. A row in Table 3 represents the transit information for a slab of pavement, with the superior sample-level label noted in column 2. Table 3 also provides the entry time to the slab, the average speed of the aircraft as it transits the slab, and the duration of the aircraft on the slab. The last two columns in Table 3 provide the flight id of the next aircraft to enter the slab after the current flight and the time between successive flights.

Table 3.
Properties of the Region Database Arrivals Crossing Pavement Slabs of Sample R00-01-113.

flight id	time entry	average speed (m/s)	time in region (min)	successive flight id	time to next entry (min)
DAL220149079606 *20120809T001722*	20120809T002130	10.7	0.02	**DAL2210**49081892 *20120809T001934*	1.8
DAL221049081892 *20120809T001934*	20120809T002318	13.4	0.02	**TRS648**49104980 *20120809T013251*	72.4

The final two columns in Table 3 can be used to define the time history of the relief of stress imposed by successive aircraft over a single slab of pavement because the columns identify the successive aircraft (e.g., its weight, type) and the time to its entry over the same pavement slab (i.e., time for stress recovery). Referring to Table 4, a 'view' of the joined data from Table 2 and Table 3 is shown. This is the typical manner in which data generated by a database query would be represented to the user and customized to control which columns are revealed. For example, flight DAL2201 (row 1 of Table 4) landed at ATL Airport and its aircraft type is a B757-251. The flight transited one of the pavement slabs of Section R00-01-113. Given that this flight was an arrival, the more relevant weight is probably the maximum landing weight (e.g., 89,811 kg). Table 4 also indicates the time spent by DAL2201 on this slab (e.g., 0.02 min) and the average speed as it crossed the slab (e.g., 10.7 m/s). Finally, the next flight to cross this slab, DAL2210 (row 2), did so 1.8 minutes after the first flight (i.e., DAL2201 in row 1).

Table 4.
View of Flight and Region Data.

flight id	aircraft type	maximum landing wgt (kg)	time in region (min)	time to next entry (min)	average speed (m/s)
DAL220149079606 *20120809T001722*	757-251	89,811	0.02	1.8	10.7
DAL221049081892 *20120809T001934*	MD-88	63,276	0.02	72.4	13.4

Pavement engineers can use the aircraft time entry data from Table 3 to define the stress on the airport pavement. Referring to Figure 6, the number of aircraft per quarter hour is shown for those flights that transited pavement sample ids R00-02-115, R00-02-116, and R03-01-112. Note that there is a smaller number of aircraft crossing this region later in the day (about 12:00 UTC).

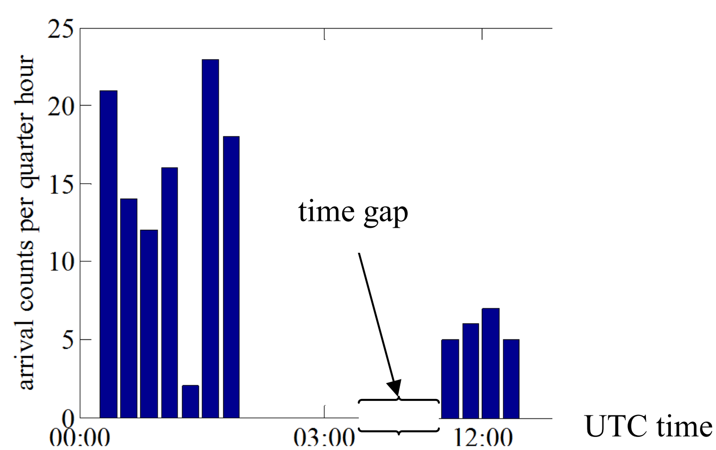

Figure 6. Aircraft Counts on a Section of Taxiway Romeo.

There are other ways to evaluate the impact of traffic loading besides counts of aircraft transiting a region. It is possible to estimate the momentum (i.e., force x time) exerted by the wheels of an aircraft on pavement slabs, which describes the loading stress on the slab and possibly its remaining longevity. This estimation is achieved by using the duration of an aircraft on a pavement slab (slab dwell time) and arrival maximum landing weight (see Table 4). The same set of flights shown in Figure 6 is shown in Figure 7 with an average momentum (kN-sec) per quarter hour. The average momentum between the time periods is similar because of the combination of heavier aircraft with longer dwell times in the later time period.

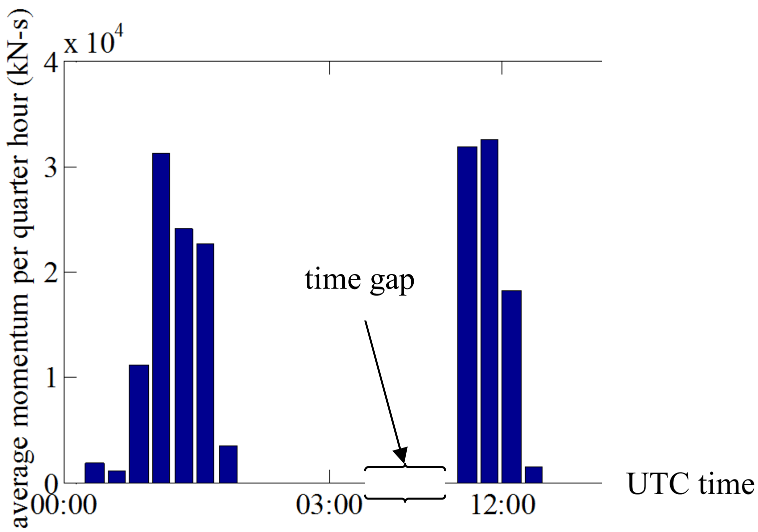

Figure 7. Average Aircraft Momentum on a Section of Taxiway Romeo.

Table 5 shows the summary statistics by aircraft type transiting the study region. In particular, the table provides totals by number of aircraft of specific types, the total maximum landing weight imposed by these arrivals, the total dwell time, and the average momentum imposed by the flights on the region. Pavement load carrying capacity is measured with load-deflectometers which quantify the response of the pavement to momentum [9] as measured in units of in-lb. Using laser devices, it should be possible to measure pavement deflection and rebound under static and transient loading (known from surveillance and aircraft data) as imposed by moving and static aircraft, respectively.

Table 5.
Summary Statistics of Traffic over a Portion of Taxiway Romeo.

aircraft		total		
type	count	maximum landing weight (kg)	dwell time in region (min)	average momentum (kN-sec)
MD-88	36	2,277,936	20.4	757,453
757-232	26	2,335,086	13.4	707,934
717-200	30	1,415,220	8.0	220,616

OPPORTUNITIES FOR PAVEMENT ENGINEERING IMPROVEMENT

Better Data, Better Decisions

Utilizing slab-specific wheel coverage and momentum data should be considered by pavement engineers, researchers, and government regulators. In particular, the availability of large amounts of momentum data could be used to define vertical stress profiles across the entire airport surface. The pavement layers respond to stresses and strains depending on the amount of time the vertical load is on a specific point (stationary load creates greater stresses and strains than a moving load, even with equal vertical magnitude). The same is true when unloading the pavement. The pavement takes time to rebound back to equilibrium state. A pavement which is loaded once every couple of hours, or days, fully recovers before the next load cycle is applied.

A pavement which is loaded repeatedly (e.g., a taxiway approach at the takeoff end of a runway) doesn't always have sufficient time to recover before the next load cycle hits, and thus may accrue some strain that it wouldn't otherwise accrue if the load repetitions occurred less frequently. This phenomenon is less problematic for concrete pavements (almost instantaneous recovery response), and much more sensitive for asphalt pavements - particularly in warm-hot periods (visco-elastic properties [time and temperature-dependent]). That said, the knowledge of duration and frequency is less important at ATL Airport (100% concrete pavements) from the perspective of stress cycle damage. Access to these data, however, still has value for ATL Airport and other airport operators/engineers throughout the world.

Proactive Airport Pavement Management

The FAA AC [2] notes the need for economic trade-off analysis when considering pavement rehabilitation plans in the near-term vs. the longer-term. The near-term costs include the delay and timing issues associated with re-routing aircraft traffic during maintenance activities. The longer-term costs consider the total life-cycle costs of the pavement to be managed as well as the longer-term shifts in demand (number of aircraft operations) and aircraft gauge size (e.g., weight) [2, chapter 1-2d]. We speculate that the need to forecast and make within-operational-day routing decisions and the forecasting of future pavement needs vs. aircraft demand and type can be served by an airport network simulation software tool. This simulation tool should accept current and future loading with adaptable taxi-paths and excess taxi-time models, and provide quick, statistical emulation of construction management and demand scenarios.

An airport simulator, as a quick screening tool for airport authorities to understand the traffic impact and congestion at an airport when considering a construction program, is in development. This approach provides a quick, statistical emulation of the airport traffic conditions based on large amounts of surface surveillance data; the simulator allows airport construction managers to evaluate different management scenarios such as the impact of closing a particular taxiway or runway on congestion and the various mitigation techniques (e.g., schedule thinning, traffic management) that may be used to abate the impacts of construction.

A prototype of this type of simulation capability helped the City of San Francisco evaluate airport management scenarios for its planned runway construction project in 2014. Scenarios of aircraft gate-holding, schedule reductions, and departure management to were evaluated to examine the trade-offs of gate-delay, taxi-out delay, fuel burn, and emissions. Figure 8 shows a screen-shot of the simulation tool for San Francisco International (SFO) Airport. This simulation shows current conditions with dual departure and arrival runways (left image, 8A), closing two of the runways with resultant departure queues (center image, 8B), and the benefit of traffic management (right image, 8C) during construction to mitigate large departure taxi-out durations.

Shown on Figure 8A are two parallel runways under current conditions (pre-construction). Arrival runways are shown with red-bordered polygons and departure runways are shown in blue borders. Moving departures on the airport surface are shown as open, blue-bordered circles; static departures appear as solid blue dots. Static arrivals are shown as solid, red dots; open, red circles indicate moving arrivals. The middle figure (8B) shows a substantial departure queue because of mixed-mode operation during construction. Figure 8C shows gate-holding of departures as solid, green dots; departure taxi-out delay has been transferred to the gate, with the concomitant reduction in delay fuel burn, emissions, and congestion in the movement area.

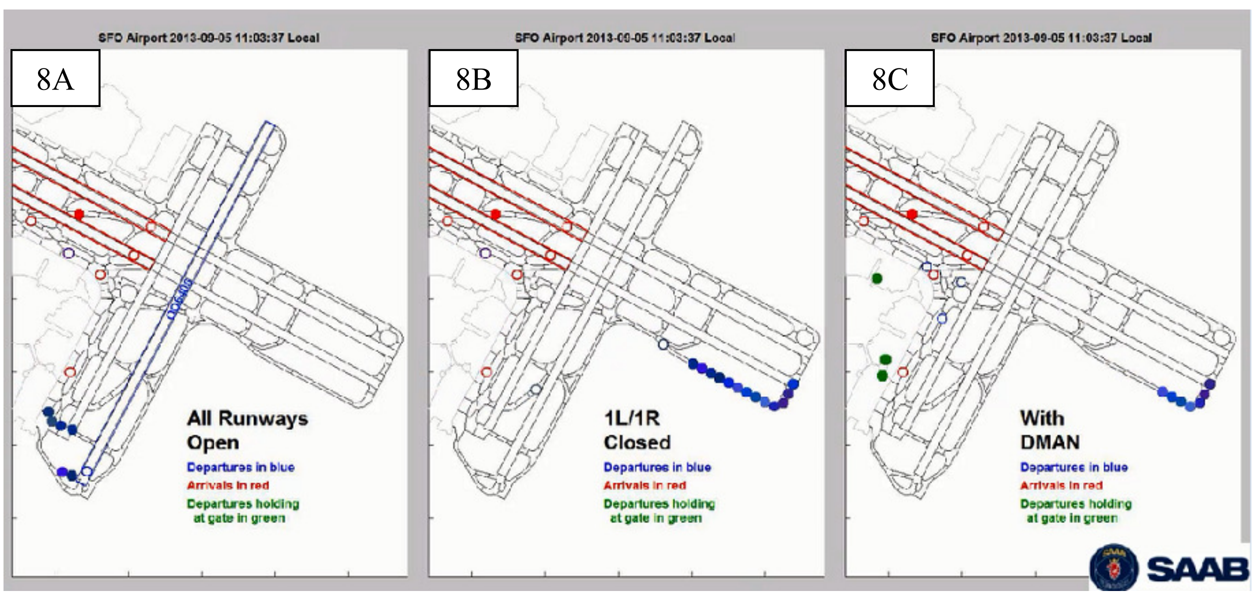

Figure 8. ‘What-if’ Views of Simulated Traffic at SFO Airport
Under Different Construction and Management Scenarios.

CONCLUSIONS

Converging massive amounts of surveillance (and other) data, “big data” analytics, and modern fast-time simulation capability provide the framework for a new methodology to assess a variety of airport operations and maintenance. This paper described the processes and artifacts of one example analysis generated from this type of airport-wide traffic database. Using slab-specific wheel coverage and momentum data to define vertical stress profiles across the entire airport surface, with the possibility of estimating cumulative and future pavement damage. A methodology for airport operations and maintenance – the use of "what-if assessment" scenario simulations based on large amounts of aircraft surveillance data; this approach should result in a better use of AIP funds and a valuation of the cost and benefit of construction to airport stakeholders in addition to the known cost of construction. As this work unfolds and is applied at ATL Airport, it should be able to develop a savings estimate from having this database to plan pavement inspection, but it is preliminary at this point to offer such an estimate.

REFERENCES

1. McNerney, M. T. and Robert Harrison, *Full-Cost Approach to Airport Pavement Management*, Handbook of Airline Economics, First Edition, Darryl Jenkins Editor, McGraw-Hill, 1995, pp. 121-130.

2. Federal Aviation Administration, Office of Airport Safety and Standards, "Guidelines and Procedures for Maintenance of Airport Pavements," Advisory Circular AC-150/5380-6B, 2007.

3. American Society for Testing and Materials (ASTM) D 5340*, Standard Test Method for Airport Pavement Condition Index Surveys*, 2012.

4. Federal Aviation Administration, Office of Airport Safety and Standards, "Airport Pavement Management System," Advisory Circular AC-150/5380-7A, 2006.

5. Boudreau, R. and Watkins, Q., "Pavement Management Using Real Time Traffic Data", Proceedings of the Airfield and Highway Pavement Conference, Los Angeles, CA, June 9-12, 2013.

6. City of Atlanta Department of Aviation, "2010 Airfield Pavement Evaluation", September, 2010 Draft, Figure 2-1: H-JAIA Pavement PCI (2010).

7. MicroPAVER, http://www2.apwa.net/bookstore/detail.asp?PC=SPR.PAVER, 2014.

8. ESRI ArcGIS, http://www.esri.com/software/arcgis, 2014.

9. View (SQL), "Wikipedia, the free encyclopedia', en.wikipedia.org/wiki/View_(SQL)

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support their colleagues at SSC, with particular gratitude toward Mssrs Waldron, Bak, and Ford, who developed key, underpinning algorithms and technology for aircraft trajectory reconstruction, aircraft geometry and aircraft "radar center-of-mass", and data processing and visualization. The authors also are grateful to SSC for its support in allowing the preparation and review of this document.