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Problematic Taxiway Geometry Study Overview

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Final Report

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16. Abstract After numerous studies concluded that nonstandard taxiway/runway geometry was a contributing factor in many runway incursions and wrong runway takeoffs/landings, the 2012 release of Federal Aviation Administration (FAA) Advisory Circular 150/5300-13A, "Airport Design," included new standards and recommendations for airport design. The FAA Office of Airports, Airport Engineering Division requested the Airport Technology Research and Development Branch to conduct additional research into taxiway geometry as the start of a 10- to 15-year improvement program to identify and correct high-incident locations on airport taxiways/runways. This research consisted of developing a geographic information system (GIS) database inventory of pilot deviation (PD) and vehicle/pedestrian deviation (V/PD) runway incursions, problematic taxiway geometry (PTG) locations, and areas currently designated as hot spots. A construction cost-estimating tool was also developed. The initial GIS database included an inventory of all PD and V/PD runway incursions at National Plan of Integrated Airport Systems (NPIAS)-towered airports reported between October 1, 2007 (when the current definition of runway incursions was adopted) and September 30, 2013. In addition, a cost-estimating tool was created to assist in preparing the rough order-of-magnitude costs associated with correcting various PTG and existing hot spots. The FAA Office of Airports and the respective Airports Regional and District Offices can use this tool to identify alternative solutions for eliminating PTG locations and the estimated cost associated with each. The cost estimate includes unit costs for all construction items adjusted for location, hub-size factor, and estimated design, construction management, and environmental assessment fees. The combination of analysis and tools will allow the FAA Office of Airports to identify nonstandard taxiway/runway areas with high incidents of PD and V/PD runway incursions and assign a program cost to each issue as part of the multi-year improvement program.					
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PREFACE

Originally titled “Development of Geographic Information System Inventory for Complex Taxiway Geometry Study,” this report was released as an internal Federal Aviation Administration (FAA) document in December 2014. After consideration, the authors and FAA are releasing this revised report to the general public.

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LIST OF ACRONYMS

AC	Advisory Circular
CFR	Code of Federal Regulations
EB	Engineering Brief
FAA	Federal Aviation Administration
GIS	Geographic information system
ICAO	International Civil Aviation Organization
NPIAS	National Plan of Integrated Airport Systems
OI	Operational incident
PD	Pilot deviation
PTG	Problematic taxiway geometry
RSAT	Runway System Action Team
V/PD	Vehicle/pedestrian deviation

EXECUTIVE SUMMARY

After numerous studies concluded that problematic taxiway/runway geometry was a contributing factor in many runway incursions, the 2012 release of Federal Aviation Administration (FAA) Advisory Circular (AC) 150/5300-13A, “Airport Design,” included new guidance for airport design. The FAA Office of Airports, Airport Engineering Division, requested the Airport Technology Research and Development Branch to conduct additional research into taxiway geometry as the basis of a 10- to 15-year improvement program to identify and correct high-incident areas on airport taxiways/runways. The resulting study consisted of developing a geographic information system (GIS) database inventory of runway incursions and problematic taxiway geometry (PTG) locations and areas currently designated as hot spots. A spreadsheet-based tool capable of generating rough order-of-magnitude cost estimates necessary for the improvement program was also developed.

The initial GIS database included an inventory of pilot deviation (PD) and vehicle/pedestrian deviation (V/PD) runway incursions that occurred at National Plan of Integrated Airport Systems (NPIAS)-towered airports reported from October 1, 2007 (when the current definition of runway incursions was adopted) to September 30, 2013. The initial geodatabase was created using ESRI® ArcGIS® software. The database contains four data layers: (1) a basemap showing aerial and satellite imagery; (2) a diagram layer containing georeferenced, FAA airport diagrams; (3) a geometry layer, containing both existing FAA-designated hot spots and problematic taxiway geometry (PTG) locations identified during the study; and (4) an incident layer, depicting georeferenced points representing the locations of PD and V/PD runway incursions.

Each PTG location included in the study was also assigned an incident category based on the peak number of annual associated incidents. In the initial database inventory there were 5099 PD and V/PD runway incursions, 6701 PTG locations, and 603 hot spots georeferenced at all NPIAS-towered airports (516 airports at the time of the study). Of the 603 existing hot spots, 66 had a peak annual incident rate greater than 3 (identified as the highest incident, Category 1A). There were also 53 PTG locations that were not identified as hot spots at the time of the incidents, but, like Category 1A, had a peak annual incident rate greater than 3 (identified as Category 2A). The most common PTG issues included: short taxiway distances from a ramp/apron area to a runway (3871 locations); direct taxi access from the ramp/apron area to the runway (2730 locations); and taxiways intersecting runways at less than a right angle (2403 locations). The latest revision to AC 150/5300-13A identifies the latter two situations as nonstandard airfield designs.

In addition, a cost-estimating tool was created to assist in preparing rough order-of-magnitude costs associated with correcting various PTG and existing hot spots. The FAA Office of Airports can use this tool to assist in developing alternative solutions for eliminating PTG locations and the estimated cost associated with each. The cost estimate includes unit costs for major construction items adjusted for location, hub-size factor, and estimated design, construction management, and environmental assessment fees.

The combination of analysis and tools will assist the FAA Office of Airports to identify nonstandard taxiway/runway areas with high-incidents of PDs and V/PDs and assign a program cost to each issue as part of this multi-year improvement program.

1. INTRODUCTION.

Preventing runway incursions continues to be a priority for the Federal Aviation Administration (FAA). In 2007, the FAA adopted the International Civil Aviation Organization (ICAO) definition of a runway incursion, “any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle, or person on the protected area of a surface designated for the landing and take-off of aircraft” [1]. Runway incursions present a serious safety risk by creating potentially life-threatening conflicts between aircraft, vehicles, and/or pedestrians [2]. Studies completed in recent years concluded that problematic taxiway geometry (PTG) was a contributing factor in many runway incursions [3].

The FAA Office of Airport Safety and Standards, Airport Engineering Division, analyzed incidents and/or accidents resulting from runway incursions, taxiway confusion, and wrong runway takeoffs/landings. This analysis prompted the FAA to revise specific standards and recommended taxiway designs that improve safety. These focused design standards and recommendations are detailed in Advisory Circular (AC) 150/5300-13A, “Airport Design,” Chapters 3 and 4, and Engineering Brief (EB) 75, “Incorporation of Runway Incursion Prevention into Taxiway and Apron Design” [3 and 4].

Subsequently, the FAA requested the Airport Technology Research and Development Branch to conduct additional research into nonstandard taxiway/runway geometry as the basis of a 10- to 15-year improvement program to correct high-incident locations categorized in this study. This began the development of a geodatabase inventory of pilot deviation (PD) and vehicle/pedestrian deviation (V/PD) runway incursions and PTG locations.

In addition to the geodatabase and the associated inventory data, a cost-estimating tool was created to develop the rough order-of-magnitude costs associated with correcting these PTG locations and those known as hot spots. The cost estimate includes unit costs for the major construction items adjusted for location, hub-size factor, and estimated design, construction management, and environmental assessment fees. Location cost factors were obtained from the *RSMeans Building Construction Cost Data* (2014 Edition) [5].

The combination of tools is intended to allow the FAA to identify geometry problems and assign each an improvement cost as the basis for developing overall program costs for each region.

2. OBJECTIVES.

There were two main objectives to this study. The first was to create a geodatabase of the following data related to runway incursions, surface incidents, and PTG. The geodatabase includes the following:

- Location and categorization of PTG locations at each towered airport
- Georeferenced points depicting PD and V/PD runway incursions and other surface incidents during the study period

- Associations established, where applicable, between the locations of airport design issues and locations of runway incursions and other surface incidents
- Inclusion of airport characteristics for sorting purposes (e.g., size, enplanements, operations, and location)

The second objective was to then use the geodatabase and associated data and conduct analysis to identify high-incident locations.

3. THE FAA GEOMETRY STANDARDS.

Previously, the FAA conducted a study [6] using data from 1997 to 2003, in which runway incursion locations that occurred at 75 airports were plotted on airport diagrams [6]. This study also focused on PD and V/PD runway incursions [6]. By examining these runway incursion locations, it was found that certain taxiway locations were associated with disproportionately more runway incursions than others [6]. This led to the identification of certain taxiway geometry configurations associated with higher rates of incursions [6]. The FAA created a new designation hot spot, which became effective November 22, 2007 [7]. Hot spots are locations identified on airport diagrams that notify pilots and vehicle operators of areas deemed to be particularly hazardous [7]. These areas either have a history of runway incursions or present an increased risk during surface operations [7].

The ICAO published a document in 2007 that cited “complex or inadequate aerodrome design” as one of the significant factors increasing the probability of runway incursions [2]. It specifically mentions the following as common factors in increasing confusion and reducing situational awareness:

- “The complexity of the airport layout including roads and taxiways adjacent to the runway;
- Insufficient spacing between parallel runways;
- Departure taxiways that fail to intersect active runways at right angles; and
- No end-loop perimeter taxiways to avoid runway crossings.” [2]

In November 2007, the FAA Airport Engineering Division (AAS-100) released EB 75 [4]. EB 75 was created in response to the previous research linking runway incursions to certain types of airport design. It also highlighted safety concepts and made airport layout recommendations to be implemented in AC 150/5300-13A [3]. This AC, released on September 28, 2012, identifies guidelines to be taken into consideration when designing airport layouts, including but not limited to:

- Avoid wide expanses of taxi pavement entering a runway.
- Limit runway crossings.
- Avoid dual-purpose pavements.

- Increase visibility of runway holding position signs.
- Do not design taxiways that lead directly from an apron to a runway. [3]

Each factor was designed to both reduce confusion when navigating the airport and promote situational awareness for pilots, vehicle operators, and pedestrians [3].

4. GEODATABASE INVENTORY.

The database contained four data layers: (1) a basemap showing aerial and satellite imagery; (2) a diagram layer with georeferenced, FAA airport diagrams; (3) a geometry layer, both existing FAA-designated hot spots and problematic geometry locations identified during the study; and (4) an incident layer, depicting georeferenced points of the locations of PD and V/PD runway incursions.

The airports included in the study were all NPIAS towered airports. Although the probability is high that problematic taxiway layouts also exist at non-towered NPIAS airports, these airports were excluded from the current research because they are not required (or do not have the capacity) to record runway incursions.

The inventory was initially built state-by-state for the entire United States, grouped by FAA region, and then combined into a single, unified database. This approach allowed the verification of interim data before producing the final inventory at a national scale. The inventory was provided in both Microsoft[®] Excel[®] and GIS format to allow the research team to analyze the data in either format.

4.1 BASEMAP.

The basemap served as the foundation onto which layers of data were added. This base layer contains the World Imagery hosted by Esri[™] on ArcGIS[®] Online [8], a sample image of which is shown in figure 1. World Imagery consists of satellite and aerial imagery that is continuously updated at a 0.3-meter resolution for the contiguous United States and at 1-meter resolution or better for the rest of the world.

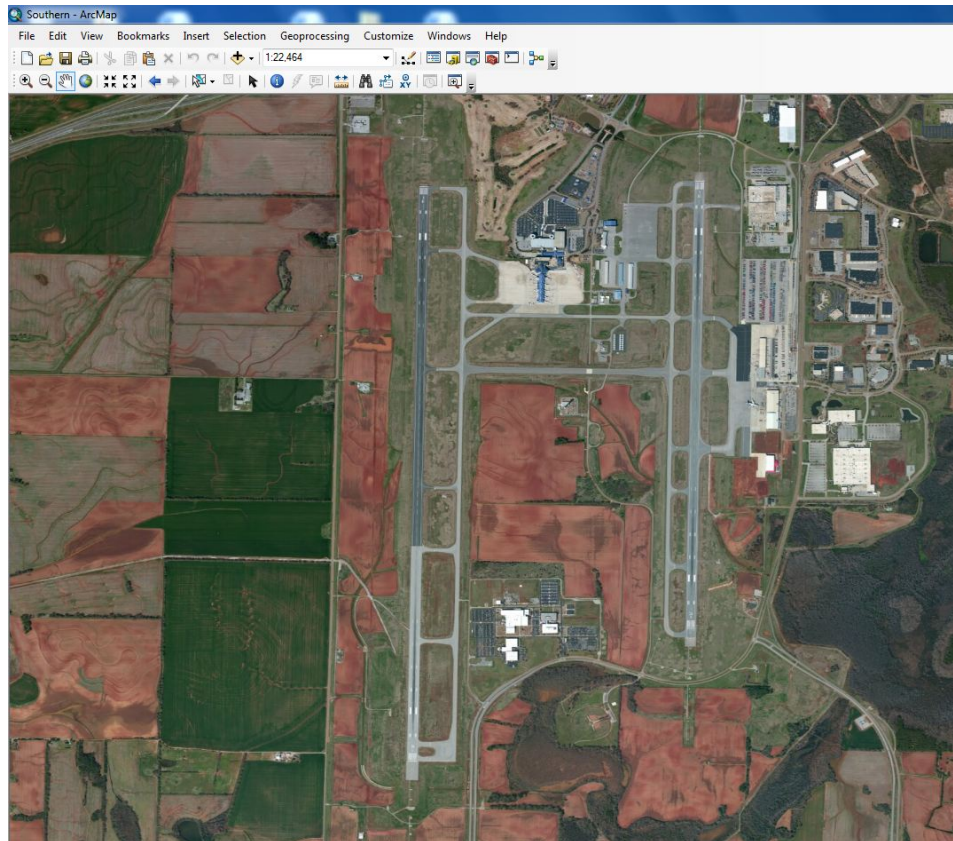


Figure 1. Basemap Imagery

4.2 AIRPORT DIAGRAMS.

For the next layer, airport diagrams were superimposed on the basemap, as shown in figure 2. The airport diagrams were inserted as raster images and are grouped by individual state. Raster data is the way that GIS displays photographic imagery—as a matrix of cells displayed in a grid. These semitransparent, georeferenced images assist with visually identifying and confirming airport features, such as runways and taxiways, as well as current hot spot locations. To approximate the scale and alignment of the aerial imagery in figure 2, multiple control points were used to match locations on the diagrams with locations on the basemap imagery. In some instances, the airport diagrams depict recently completed airport construction projects, which are not yet reflected in the aerial imagery.

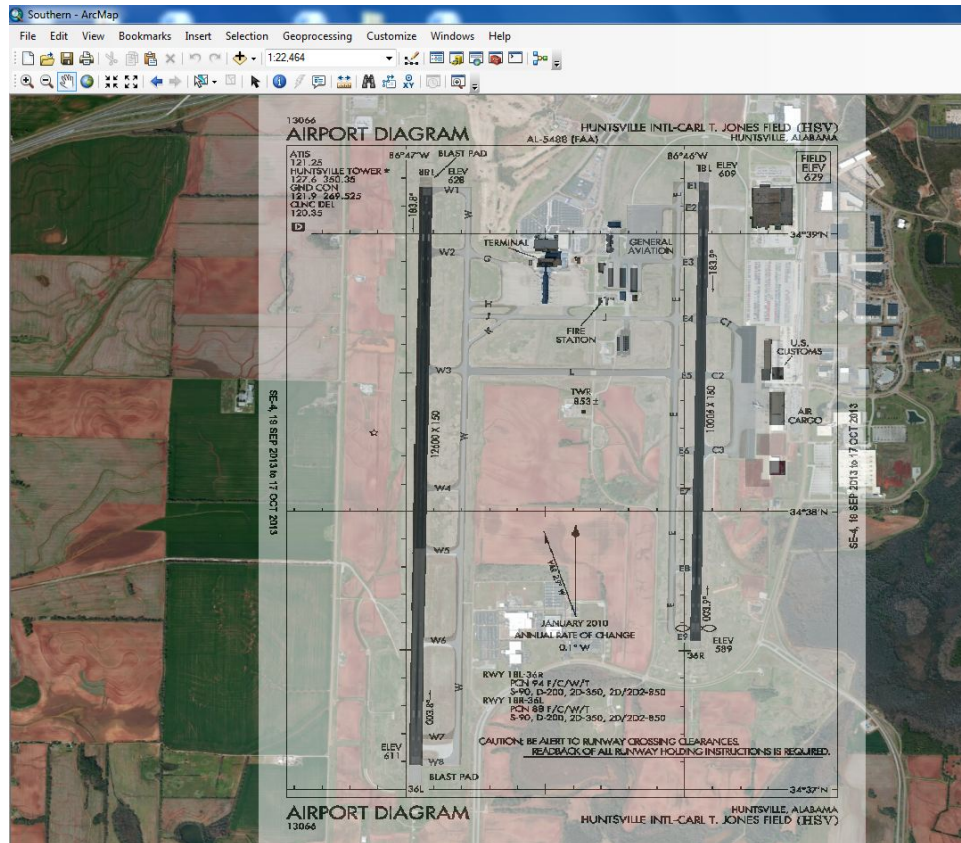


Figure 2. Airport Diagram Depiction

4.3 GEOMETRY LAYER.

The geometry layer was designed to locate two types of data points. The first data point depicted a location already designated as a hot spot on the office FAA airport diagram, while the second data point depicted a location with problematic taxiway design not currently designated as a hot spot.

4.3.1 Hot Spots.

The first type of geometry location point is a hot spot. According to the FAA, areas identified as hot spots often have a history of runway incursions or surface incidents, or are areas known to require increased vigilance from air traffic control. They are designated by local Runway Safety Action Teams (RSAT). RSATs are made up of airport users that meet to discuss safety issues involving moving around the airport and airspace and make recommendations to enhance safety. Hot spots remain charted on the airport diagram until the factors that contribute to the increased risk are mitigated [7]. An example of a hot spot marking, labeled HS 1, is shown in figure 3.



Figure 3. Hot Spot Depiction on Airport Diagram

To georeference existing hot spot locations, points were created in the database and numbered according to the current airport diagram. The three-letter airport identifier was also added to each existing hot spot point (e.g., BWI-HS1).

4.3.2 Problematic Taxiway Geometry.

The second type of geometry location point includes all other locations that met the criteria to be considered PTG. This criterion is described in EB 75, and relates to a taxiway's "location, alignment, width, and operational use" [4]. Also referenced were the criteria detailed in the taxiway design standards provided in AC 150/5300-13A [3] and airport geometry data elements identified by the Office of Runway Safety (AJI-14) [9]. This study focused on the guidance-documented PTG, plus other PTG to obtain the 19 most common geometry elements associated with a runway/taxiway intersection, known as geocodes. The points identified as having PTG were depicted as yellow circles when viewed in the geodatabase, as shown in figure 4.



Figure 4. Problematic Taxiway Geometry Locations

PTG points were located by analyzing an airport's diagram and aerial imagery. Where applicable, PTG points were located at the intersection of the runway or taxiway centerline and a runway holding position marking. Each location identified was assigned a code consisting of the airport's three-letter identifier and a sequential number (e.g. ORD-01, ORD-02, etc.).

Each PTG location was coded with one or more (up to 5) of the geocodes listed below.

1: Y-shaped taxiways crossing a runway [3]

Multiple taxiway entrances at one runway location, such as Y-shaped connectors, present opportunities for ground navigation errors as a result of wide expanses of pavement, difficulties in reading signage, etc., which promote the potential for runway incursions and for aircraft vacating one runway to enter a wrong taxiway or a different runway [3]. An example of this is shown in figure 5. Limiting the routing options available to pilots on each runway entrance or exit may help to avoid runway confusion.



Figure 5. Y-Shaped Taxiways

2: *Wrong runway events*

Locations that experience a high frequency of wrong runway landings or takeoffs can also be associated with other airport geometry issues, such as runway thresholds in close proximity, as shown in figure 6.

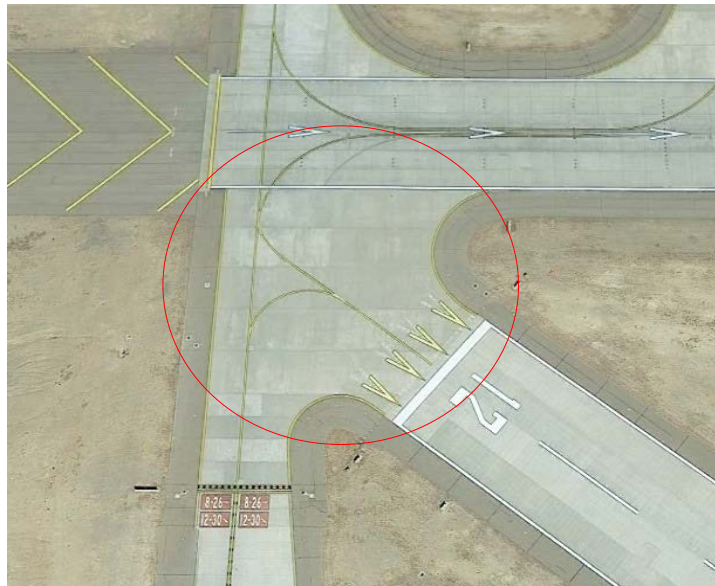


Figure 6. Runway Thresholds Susceptible to Wrong Runway Landings and Takeoffs

3: Wide expanses of taxi pavements entering or along a runway [4]

Wide pavements typically require nonstandard sign placement with respect to the taxiway centerline, lack of sign placement, and/or further placement of signage from the taxiway centerline than prescribed by the standard. These conditions have the capability to reduce the pilot's ability to see visual cues, especially in low-visibility conditions [4]. Wide pavements are especially critical at runway entrance points, as shown in figure 7 [4].

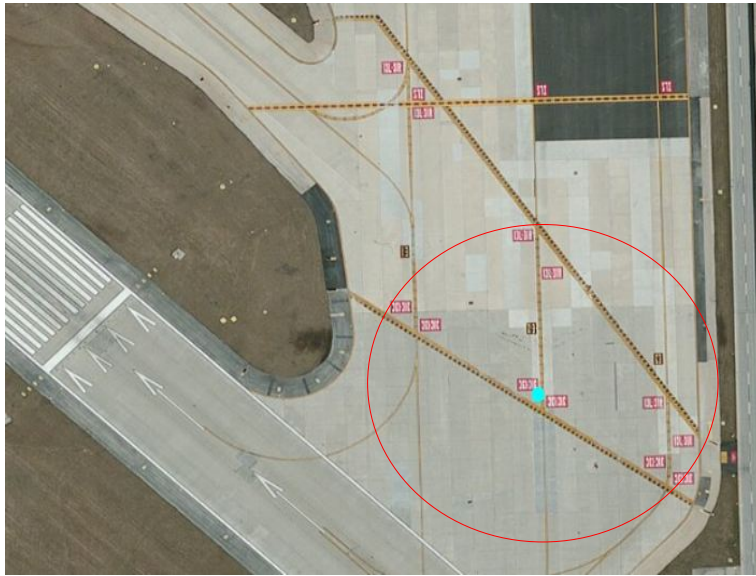


Figure 7. Wide Expanse of Pavement at Runway Entrance

4: Convergence of numerous taxiway types entering a single runway [3]

Taxiway configurations with multiple taxiways entering a runway create large expanses of pavement that make it difficult to provide proper signage, marking, and lighting, as shown in figure 8 [3]. This configuration also violates the three-node concept of taxiway design as described in AC 150/5300-13A [3].



Figure 8. Converging Taxiway Types for a Runway

5: High-speed exit crossing a taxiway [4]

A high-speed exit that crosses or connects with another taxiway directly entering a runway can result in a runway incursion, as shown in figure 9 [4]. The main safety issues with this design are the difficulties with marking, signing, and lighting the resultant wide expanses of pavement.



Figure 9. High-Speed Exit Taxiway Crossing

6: *Two runway thresholds in close proximity* [3]

Configurations where runway thresholds are too close together are not recommended, as shown in figure 10. This type of configuration can be confusing to pilots, resulting in runway incursions, as well as wrong runway takeoffs [3].



Figure 10. Runway Thresholds in Close Proximity

7: *Short taxiways (stubs) between runways* [3]

Short taxiways between intersecting runways (especially a taxiway within the runway safety area of both runways), as shown in figure 11, can cause aircraft exiting the runway to almost immediately encounter another aircraft in runway holding position. This configuration may not be expected by the pilot, resulting in a failure to hold short and lead to a runway incursion [3]. This same situation may make it impossible to hold aircraft or vehicles between the two runway holding positions.

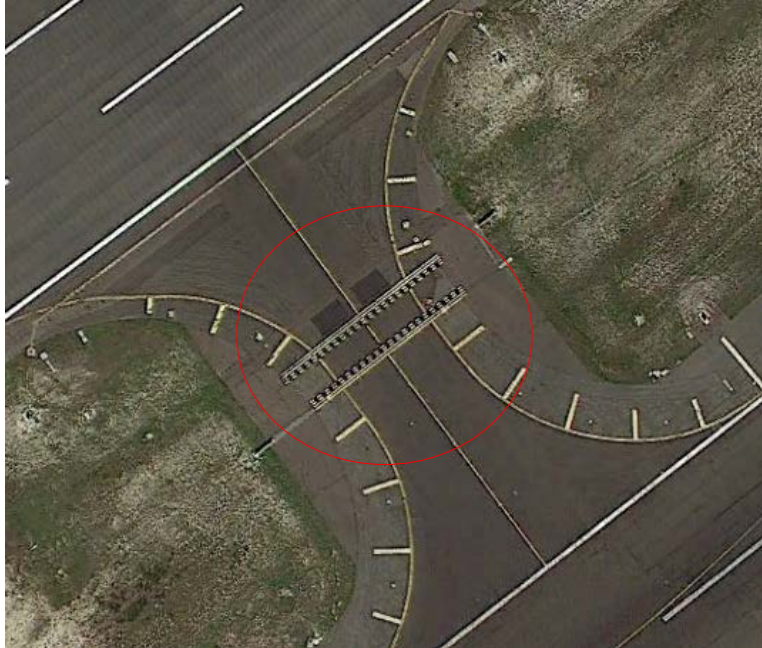


Figure 11. Short Taxiway Between Runways

8: Direct taxiing access to runways from ramp areas [3]

Taxiways that lead directly from an apron to a runway, as shown in figure 12, are not recommended. These configurations may create the false expectation of a parallel taxiway prior to the runway (basic design standard), which could lead to confusion and runway incursions [3].



Figure 12. Direct Access to Runway From Ramp

9: An aligned taxiway entering runway ends [3]

An aligned taxiway is one in which the taxiway centerline coincides with a runway centerline [3], as shown in figure 13. These typically occur in areas where the runway end was permanently relocated to a new location and a new perpendicular entrance taxiway was not provided onto the new runway. An aligned taxiway has been shown to cause runway incursions in addition to placing the taxiing aircraft in direct line with an aircraft that may be taking off or landing. The result is the inability to use the runway while the taxiway is occupied, along with the possible loss of situational awareness for the pilot [3].

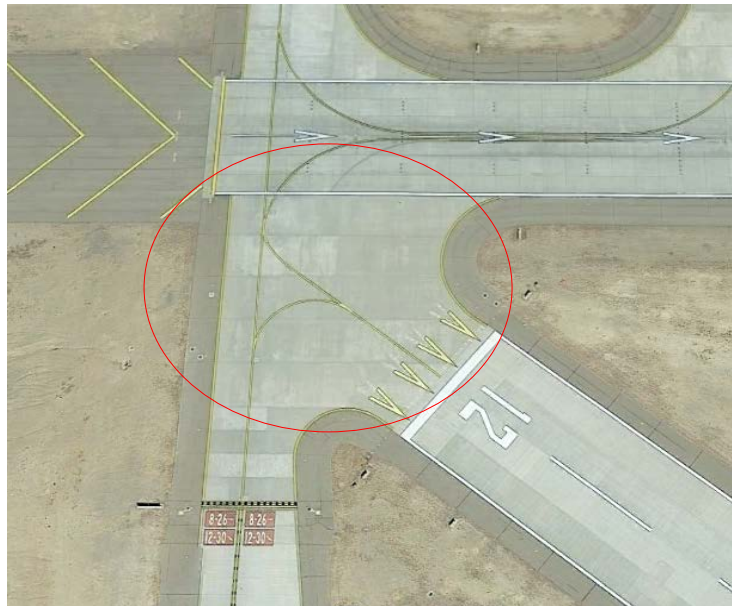


Figure 13. Aligned Taxiway

10: Nonstandard markings and/or signage placement [9]

Nonstandard markings and/or signage could include, but are not limited to, overlapping hold bars, nonstandard hold bar placement, and runway intersections with multiple hold lines. Nonstandard location or lack of placement and visibility of the markings, lighting, and signage on taxiways, as shown in figure 14, decreases the pilot's situational awareness within the area/location. [9].



Figure 14. Nonstandard Marking Placement

11: Greater than three-node taxiway intersection [3]

All taxiway intersections should be constructed with the three-node design principle in mind [3]. This principle reduces the number of taxiways intersecting in a single location, which allows for proper placement of airfield markings, signage, and lighting. An intersection that has greater than three nodes, as shown in figure 15, is considered problematic. This may lead to pilot confusion and, if located at or near runway entrance points, can lead to incursions [3].

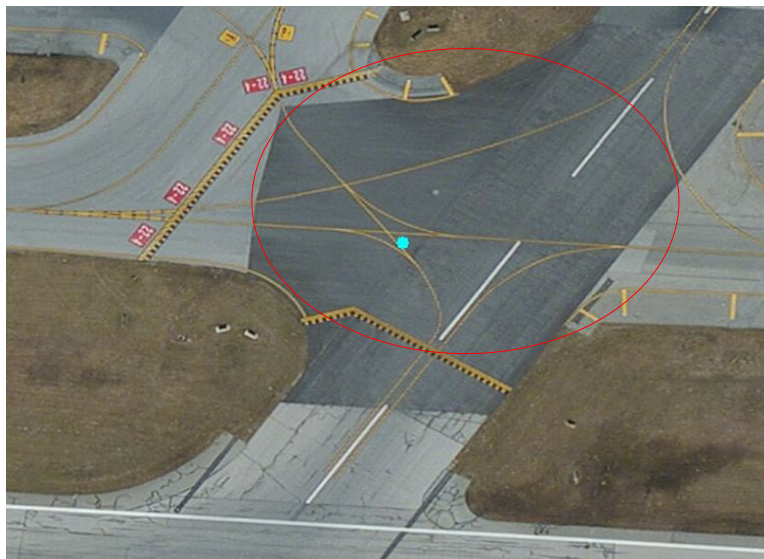


Figure 15. Intersection Greater Than Three Nodes

12: Taxiway connection to V-shaped runways [9]

One taxiway leading to an area with multiple runway thresholds located in close proximity to one another, as shown in figure 16, can result in hold lines in short proximity. This can result in a failure to hold short and a runway incursion [9].



Figure 16. Taxiway Connecting V-Shaped Runways

13: Taxiway intersect runway at other than a right angle [3]

Right-angled intersections are the standard design for all taxiway/runway entrance intersections [3]. Right-angled intersections provide the best visual perspective to a pilot of the entire runway (left and right) when approaching the intersection [3]. If a taxiway intersects a runway at any angle other than a right angle, as shown in figure 17, the chance of a landing/departing aircraft colliding with an errant taxiing aircraft (runway incursion) increases [3].

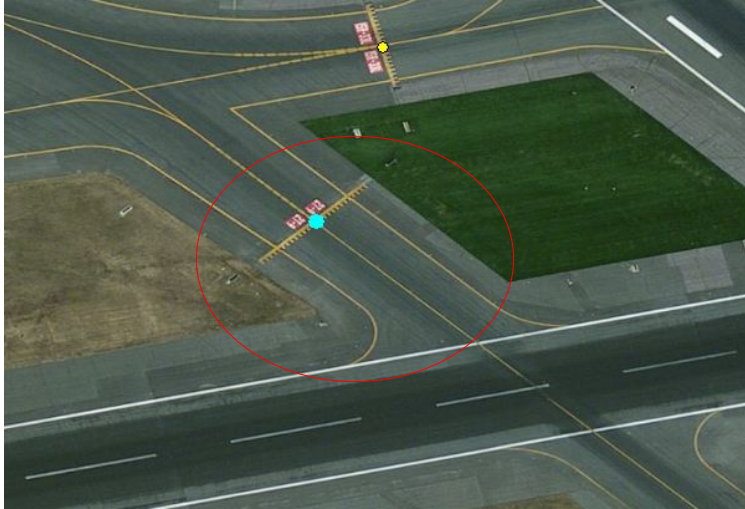


Figure 17. Taxiway Intersecting Runway at Other Than a Right Angle

14: Short taxi distance from ramp/apron area to a runway [9]

A short taxi distance, compared to a direct ramp-to-runway configuration, between the terminal and the runway requires pilots to complete the same number of checklist items in a shorter timeframe than longer taxi routes. Therefore, during the head-down period, the pilot(s) may taxi through the runway hold line (loss of pilot's situational awareness) [9]. An example of this type of geometry is shown in figure 18.



Figure 18. Short Taxi Distance to Runway From an Apron

15: High-speed exits leading directly onto another runway [4]

A high-speed exit taxiway that provides a direct route from one runway across another runway is especially problematic, particularly for closely spaced runways and dual visual runways [4]. Exiting aircraft may have little to no time to position themselves before

crossing the adjacent runway's hold line. This configuration, as shown in figure 19, has resulted in runway incursions.



Figure 19. High-Speed Exit Leading Directly to Another Runway

16: Taxiway coinciding with the intersection of two runways [3]

Taxiway configurations where a single taxiway enters a multiple runway intersection in a single area, as shown in figure 20, can create various difficulties. Large expanses of pavement may make it difficult to provide proper placement of signage, marking, and lighting [3]. In addition, this may be a contributing factor in wrong runway takeoffs.

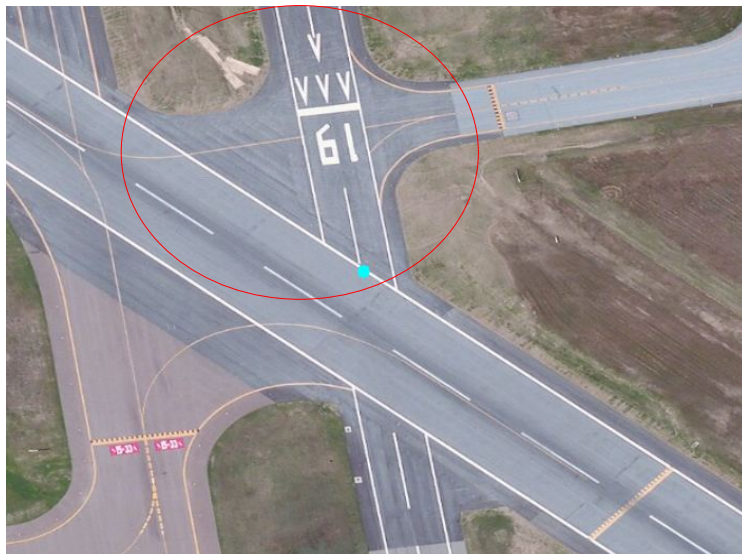


Figure 20. Taxiway Coinciding With Intersection of Two Runways

17: Use of a runway as a taxiway [3]

Runways used as taxiways, as shown in figure 20, can lead to confusion, wrong runway takeoffs, or runway incursions. A runway should always be clearly identified as a runway and only a runway [3].

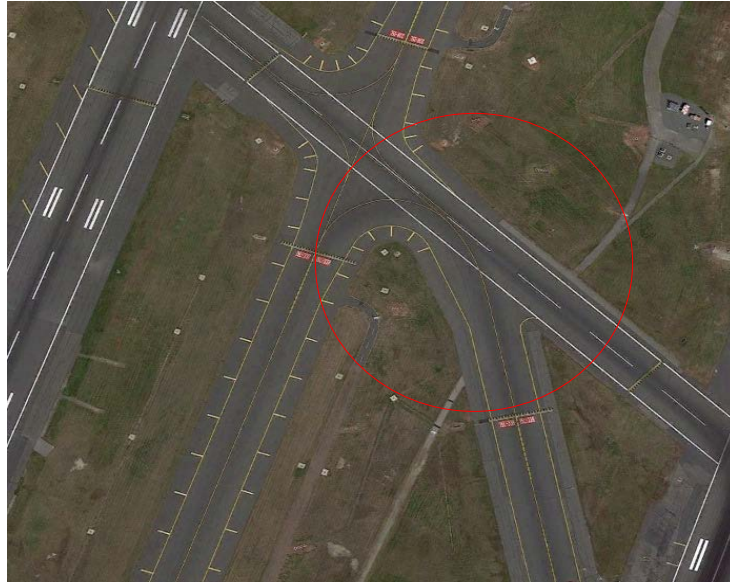


Figure 21. Using a Runway as a Taxiway

18: Displaced threshold with holding position marking on parallel taxiway [3]

This placement is unexpected by the pilot and may cause the pilot to ignore/not expect the hold position point, resulting in a possible runway incursion. An example of a problematic displaced runway threshold is shown in figure 22.



Figure 22. Displaced Threshold With Holding Position Marking on Parallel Taxiway

Additional nonstandard geometries from AC 150/5300-13A, Chapters 3 and 4 [3], and EB 75 [4] were also considered as a means of identifying PTG locations, but did not specifically have one of the 18 geocodes listed in this section. These PTGs were captured in another category—Geocode 99: Miscellaneous. This geocode includes runway intersection sign and marking standards, nonsequential taxiway designation schemes, absence of full-length parallel taxiway, and intersections in the middle third of runways.

As an example, in the case of the PTG location shown in figure 23, three different geocodes were applied. These geocodes include numbers 8, 14, and 13, as shown in table 1.

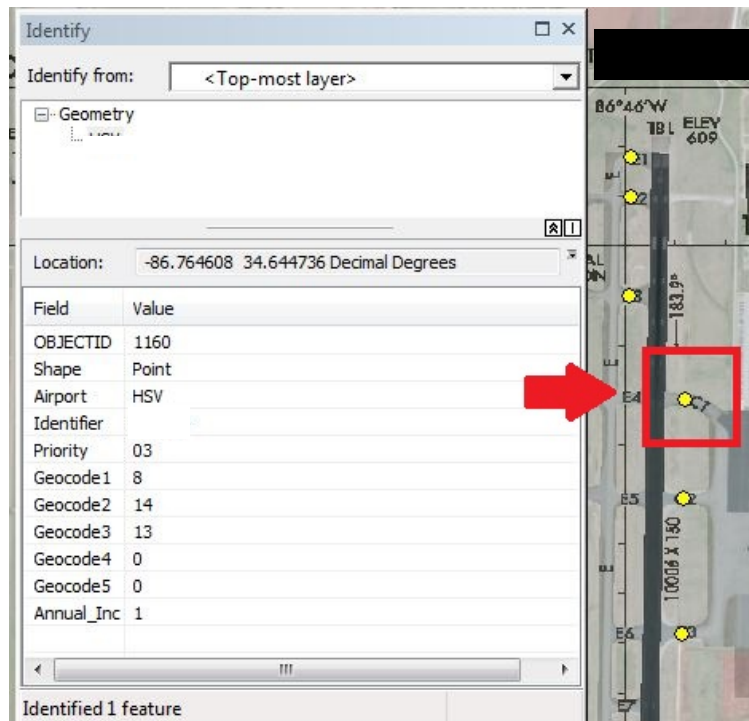


Figure 23. The PTG Location Attribute Table With Associated Geocodes

Table 1. Geocode Listing

Geo Code	Problematic Geometry Definition
0	No geometry issues
1	Y-shaped taxiways crossing a runway
2	Wrong runway events
3	Wide expanses of taxi pavements entering or along a runway
4	Convergence of numerous taxiway types entering a runway
5	High-speed exit crossing a taxiway
6	Two runway thresholds in close proximity
7	Short taxiways (stubs) between runways
8	Direct taxiing access to runways from ramp areas
9	An aligned taxiway entering runway ends
10	Nonstandard markings and/or signage placement (e.g., overlapping holdbars, nonstandard holdbar placement, runway intersections with multiple hold lines)
11	Greater than three-node taxiway intersection
12	Taxiway connection to V-shaped runways
13	Taxiway intersects runway at other than a right angle
14	Short taxi distance from ramp/apron area to a runway
15	High-speed exits leading directly onto another runway
16	Taxiway coinciding with the intersection of two runways
17	Using a runway as a taxiway
18	Unexpected holding position marking on parallel/entrance taxiway
99	Miscellaneous: <ul style="list-style-type: none"> • Nonsequential taxiway designation schemes • Absence of full-length parallel taxiway • Taxiway intersection along the middle third of a runway • Runway intersection sign and marking standards

4.4 INCIDENT LAYER.

The incident layer was added to the geodatabase to visually show the specific location of each runway incursion. Runway incursions are classified by the FAA as either a PD, V/PD, or operational incident (OI) [1]. The classification is determined by which party most directly caused the incursion [2]. A PD occurs when a pilot deviates from an FAA regulation and enters a runway without clearance [1]. The V/PD is described as an occurrence involving a vehicle

operator, person on foot, or a non-pilot aircraft operator “entering any portion of the airport movement areas (runways/taxiways) without authorization from air traffic control” [1]. An OI is described as an

Action of an Air Traffic Controller that results in less than required minimum separation between 2 or more aircraft, or between an aircraft and obstacles (vehicles, equipment, personnel on runways), or clearing an aircraft to take off or land on a closed runway. [1]

Because air traffic control procedures are outside the scope of this study, the geodatabase only includes PD and V/PD incidents.

The initial geodatabase included all PD and V/PD runway incursions and surface incidents reported between October 1, 2007 and September 30, 2013 at NPIAS-towered airports. Each incident point corresponds to a runway incursion or surface incident report. An example of how runway incursions are depicted in the geodatabase is shown in figure 24.

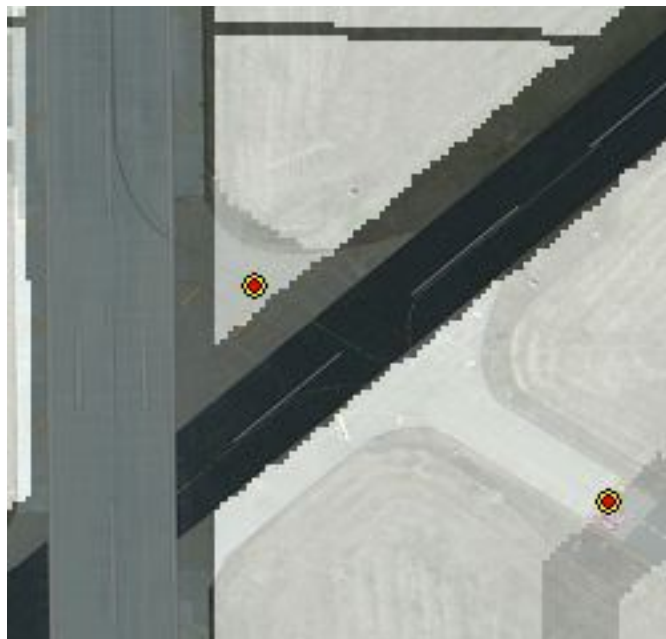


Figure 24. Runway Incursion Depiction in Geodatabase

Reports for runway incursions and other surface incidents were recorded in a Microsoft Excel spreadsheet provided by the FAA and contained the following information:

- Date of event
- Report number
- Airport code
- FAA region
- Classification as runway incursion or surface incident
- Severity category

- Incident type category
- Incident runway location
- Report narrative

All data included in the runway incursion Microsoft Excel file were retained in the geodatabase. The incursion data was georeferenced by interpreting the locations of the incident identified in the incursion report narrative. For runway incursion reports that lacked specific location descriptions in the incursion narrative, the incursion locations were placed either on the runway threshold, when identified, or the airport reference point provided by the FAA. This occurred for approximately 1% of incidents.

Table 2 shows an example of how data were collected and maintained in the geodatabase. In this example, the dates and runway incursion event number (identifier) at Mobile Downtown Airport (BFM) are captured. Each incursion point was analyzed to determine if a problematic geometry issue (geocode) existed at the location of the incursion site. If so, the location was logged with a Y in the Geometry column. If a geocode was not found at the incursion site, the Geometry column indicated the label N. The specific identifier from the geometry data layer is shown in the GeoAssoc column for all incursions that occurred near identified geometry location points. The table also include information such as airport name, FAA region, state, whether the event was a runway incursion or surface incident, the severity category and type of incident, and the runway closest to the incident location.

Table 2. Runway Incursion or Surface Incident Attributes List

Incursions											
Airport	Date	Identifier	Geometr	GeoAssoc	AirportIa	Region	State	RlorSI	SeverCat	IncidCat	IncRunLoc
BFM	10/6/2011	PSOTBFM1100	N	NA	Mobile Downtown	ASO	AL	RI	D	PD	18
BFM	6/9/2013	VSOTBFM1300	N	NA	Mobile Downtown	ASO	AL	RI	D	V/PD	<Null>
BFM	1/4/2011	PSOTBFM1100	Y	BFM-HS1	Mobile Downtown	ASO	AL	RI	C	PD	14
BFM	2/23/2011	PSOTBFM1100	Y	BFM-HS1	Mobile Downtown	ASO	AL	RI	D	PD	14
BFM	3/2/2011	PSOTBFM1100	Y	BFM-HS1	Mobile Downtown	ASO	AL	RI	D	PD	14
BFM	3/14/2011	PSOTBFM1100	Y	BFM-HS1	Mobile Downtown	ASO	AL	RI	D	PD	14
BFM	4/13/2011	PSOTBFM1100	Y	BFM-HS1	Mobile Downtown	ASO	AL	RI	D	PD	14
BFM	5/31/2011	PSOTBFM1100	Y	BFM-HS1	Mobile Downtown	ASO	AL	SI	SI	PD	14
BFM	8/2/2011	PSOTBFM1100	Y	BFM-HS1	Mobile Downtown	ASO	AL	SI	SI	PD	14
BFM	3/2/2011	PSOTBFM11RS	Y	BFM-HS1	Mobile Downtown	ASO	AL	RI	D	PD	14
BFM	7/25/2012	PSOTBFM1200	Y	BFM-HS1	Mobile Downtown	ASO	AL	RI	D	PD	14
BFM	9/27/2013	PSOTBFM1300	Y	BFM-HS1	Mobile Downtown	ASO	AL	RI	D	PD	14
BFM	1/23/2013	PSOTBFM1300	Y	BFM-HS1	Mobile Downtown	ASO	AL	RI	D	PD	14
BFM	1/21/2013	PSOTBFM1300	Y	BFM-HS1	Mobile Downtown	ASO	AL	RI	D	PD	14
BFM	12/19/2012	PSOTBFM1200	Y	BFM-HS1	Mobile Downtown	ASO	AL	RI	D	PD	14
BFM	11/16/2012	PSOTBFM1200	Y	BFM-HS1	Mobile Downtown	ASO	AL	RI	D	PD	32
BFM	9/26/2012	PSOTBFM1200	Y	BFM-HS1	Mobile Downtown	ASO	AL	RI	D	PD	14
BFM	9/26/2012	PSOTBFM1200	Y	BFM-HS1	Mobile Downtown	ASO	AL	RI	D	PD	14
BFM	8/6/2012	PSOTBFM1200	Y	BFM-HS1	Mobile Downtown	ASO	AL	RI	D	PD	14

The following is an example of a narrative report that was used to identify the location of an incident.

A Cessna® C172 was issued taxi instructions to Runway 18L at intersection Echo 2 for departure. Subsequently the C172 crossed the hold short line at Echo 2 without clearance. The aircraft did not enter the runway and no conflicts reported.

The incursion narrative indicates that the incursion occurred at the Runway 18L and Taxiway Echo 2 intersection. In this case, the incursion point was georeferenced at the intersection of the

Taxiway Echo 2 centerline and the runway hold short line. The Geometry field would be logged as Y, and the GeoAssoc field would contain the associated geometry point located at the intersection, shown in figure 25.



Figure 25. Georeferenced Runway Incursion

When an incursion was the result of an aircraft landing or departing a runway without being properly cleared by air traffic control, the incursion points were placed on the center of the threshold of the runway affected. This condition was indicated in the following narrative:

A Cessna C172, operated by a solo student pilot, was cleared to land on Runway 18 which was acknowledged. The C172 landed then departed Runway 18 without clearance. No conflicts reported.

Therefore, the runway incursion was plotted at the position, centered on the runway 18 threshold, as shown in figure 26.



Figure 26. Landing Aircraft Incursion

It should also be noted that in some cases, the method of georeferencing incidents can make runway incursions appear more concentrated in a certain area than they would be in reality. This is because some surface incident or runway incursion report narratives failed to provide sufficient detail to establish a definite location on the airfield. In these situations, the incident

point was depicted at the center of the most probable location indicated in the narrative. For example, one narrative stated the following:

A Cirrus® SR22 entered and exited Taxiway Alpha while repositioning aircraft without clearance. No conflicts reported.

Taxiway Alpha runs the entire apron area length, as shown in figure 27; therefore, it cannot be known with certainty where on the taxiway this incident occurred. Consequently, the incident was depicted at the half-way point of this taxiway. Similar undefined narratives also existed for the same airport, resulting in several other points being collocated at this position, based on similar reasoning. In such cases, discretion is required to interpret the applicability of these points for use in planning.



Figure 27. Unidentified Incident Location

4.5 ADDITIONAL DATA.

Additional external data included in the geodatabase and the Microsoft Excel spreadsheet for the airports and PTG points include:

- 2012 operations
- 2012 enplanements
- Hub size category (i.e., large hub, medium hub, small hub)
- Title 14 Code of Federal Regulations (CFR) Part 139 airport status
- Incident level for runway incursions

Airport operations and enplanements for 2012 were obtained from the Air Traffic Activity Data System (ATADS), Passenger Boarding (Enplanement) and All-Cargo Data [10] for United States airports, respectively. Airport hub size categories were derived from a combination of sources, including the 2013-2017 NPIAS Report to Congress [11]. The Title 14 CFR Part 139 status was obtained from the 14 CFR Part 139 Airport Certification Status List, as of the January 21, 2014 update [12].

5. CATEGORIZATION AND INVENTORY.

5.1 FORMAT/METHODOLOGY.

The inventory was reported in Esri ArcGIS, Microsoft Excel, and Google Earth™ mapping application in Keyhole Markup Language (KML) file database formats containing various information, including the number of runway incursions, category of incidents (frequency of runway incursions), and geocodes, which are defined in section 4.

Each location was then categorized based on the number of runway incursions associated with the identified problematic geometry point or existing hot spot.

5.2 CATEGORIZATION.

All locations associated with at least one runway incursion surface incident and geocode were assigned categories. The purpose of this categorization was to provide a basis for determining which locations represent the most significant safety concern and to assist in the prioritization of mitigation efforts. Two factors were considered when assigning categories: (1) whether a location was designated a hot spot and (2) the peak annual rate of incidents associated with the location over the 5-year study period. The use of the peak rather than the average was chosen to reflect the worst-case scenario and convey the maximum potential safety risk at a given location during the study period. Together, these two factors indicated locations with an elevated potential for runway incursions.

These categories are divided into two main groups. The first group, Category 1, includes locations that are existing hot spots. The second group, Category 2, includes all other non-hot spot PTG locations. Each category was further subdivided into three levels—A, B, and C—to reflect the number of peak annual incidents.

To determine the peak incident threshold, five scenarios were considered. The objective was to find a threshold that resulted in a number of locations yielding a significant number of potential projects, but not too many projects as to be impractical. Therefore, the targeted amount of locations to include in the two highest categories (1A and 2A) was between 100 and 200 locations (1.5% to 3.0% of the total). These preliminary scenarios were computed while the database was being assembled and included data from the Eastern, Great Lakes, New England, Northwest Mountain, Southern, and Southwest FAA airport regions. The projected distributions for each scenario that were calculated at that time are shown in figures 28 through 32.

Scenario 1

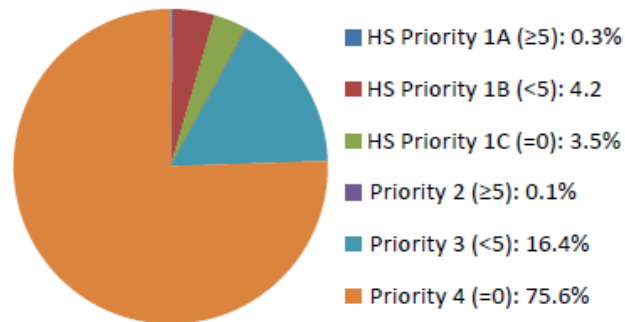


Figure 28. Category Distribution With Incident Threshold Set at 5

Scenario 2

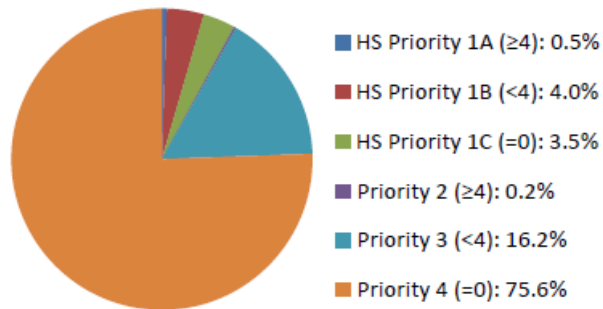


Figure 29. Category Distribution With Incident Threshold Set at 4

Scenario 3

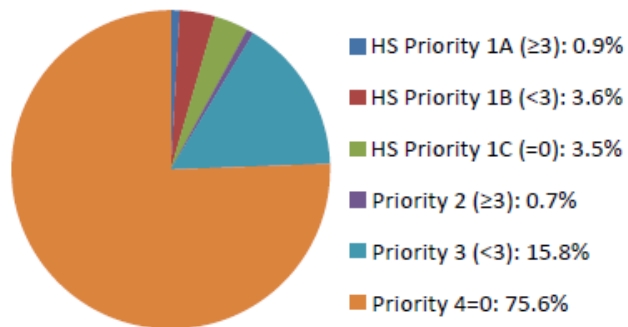


Figure 30. Category Distribution With Incident Threshold Set at 3

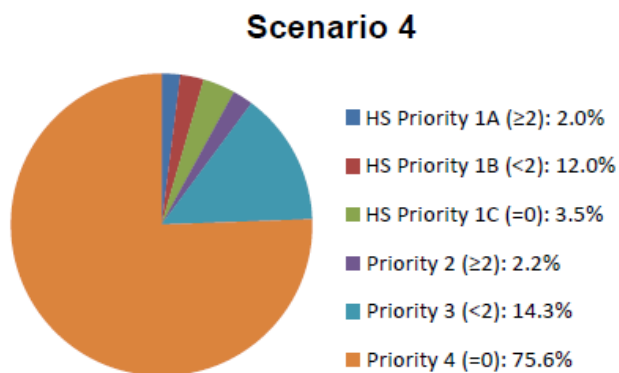


Figure 31. Category Distribution With Incident Threshold Set at 2

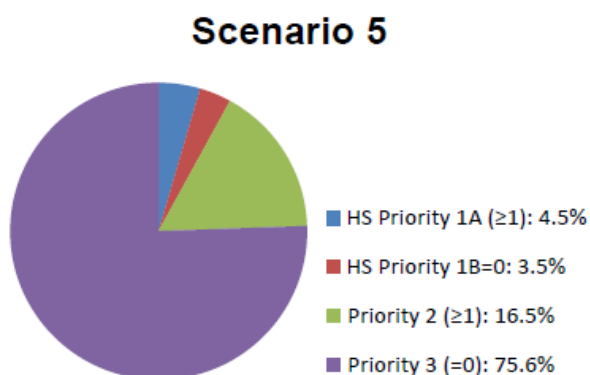


Figure 32. Category Distribution With Incident Threshold Set at 1

The incident thresholds set at 4 and 5 resulted in too few high-priority locations for program planning purposes (46 and 26 locations, respectively). The incident thresholds set at 1 and 2 yielded too many results for this purpose (294 and 1407 locations, respectively). Therefore, the incident threshold set at 3, projected to yield 107 locations was the most optimal.

As shown in table 3, this analysis resulted in defining six total categories:

Table 3. Location Category Definitions

Hot Spots		Non-Hot Spots	
Category	Peak Annual Incidents Associated with Location	Category	Peak Annual Incidents Associated with Location
1A	≥ 3	2A	≥ 3
1B	< 3 ($\neq 0$)	2B	< 3 ($\neq 0$)
1C	0	2C	0

It should be noted that although locations categorized as 2A have not been designated as hot spots, they still represent a significant safety concern. Locations with fewer than three incident occurrences (but excluding zero) were assigned categories 1B and 2B. Taxi locations without recorded surface incidents or runway incursions were assigned categories of 1C and 2C, respectively.

5.3 INVENTORY SUMMARY.

5.3.1 Geometry Category Distribution.

A total of 5099 runway incursions were georeferenced along with 6701 PTG points at 516 NPIAS-towered airports. For the purpose of this analysis, surface incidents were removed. The final distribution of the PTG points, according to the six categories outlined in section 5.2, is shown in figure 33. Of the 603 hot spots included in the study, 263 hot spots fell within Category 1C with no associated incidents. Of the remaining 358 hot spot locations with associated incidents, 274 had a peak annual incident rate of 1 or 2 reported events (Category 1B) and 66 had a peak annual incident rate of 3 or more reported events (Category 1A).

The remaining 6098 PTG points that were not hot spots contained 4792 locations that had no associated incidents (Category 2C). Of the remaining non-designated hot spot PTG points, 1253 had a peak annual incident rate of either 1 or 2 reported events (Category 2B) and 53 had a peak annual incident rate of 3 or more reported events (Category 2A).

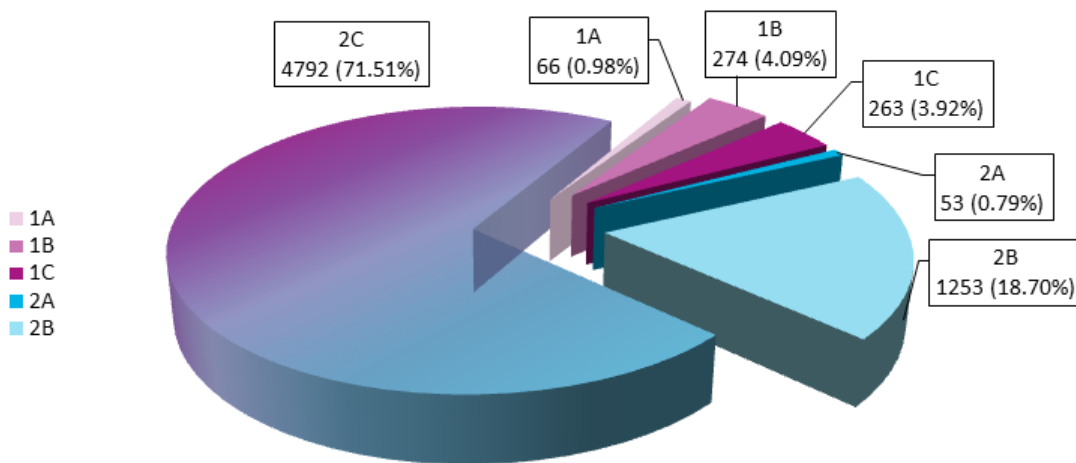


Figure 33. Geometry Location Points Category Distribution

5.3.2 Geocode Occurrences.

The geocodes assigned to each geometry location were analyzed to determine their relative levels of frequency in the database and their role in runway incursion frequency. Of the geocodes (section 4.3.2) assigned to the existing hot spot and other non-hot spot problematic geometry locations, several codes stand out as the most frequently occurring, as shown in figure 34. These include short taxiway distances from the ramp/apron to a runway

(3871 locations—Geocode 14), direct taxi access from the ramp/apron area to a runway (2730 locations—Geocode 8), taxiways intersecting runways at less than a right angle (2403 locations—Geocode 13), and wide expanses of taxi pavements entering or along a runway (1305—locations Geocode 3).

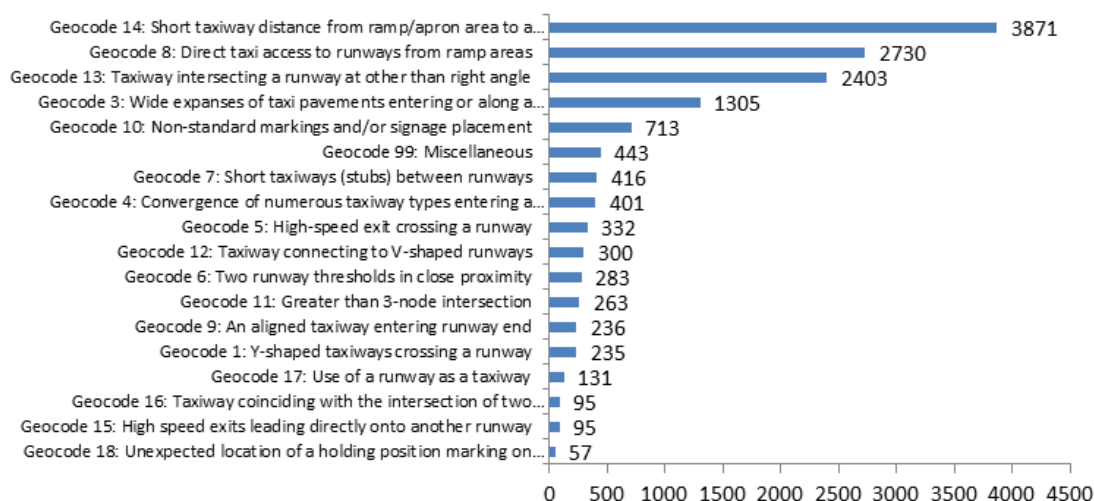


Figure 34. Geocode Occurrences at Inventoried Locations for all Categories

The most frequently occurring geocodes were generally associated with the highest number of PD and V/PD runway incursions in absolute terms. For example, as shown in figure 35, locations identified as having a short taxi distance from ramp/apron area to a runway or direct taxi access to runways from ramp areas experienced the highest number of runway incursions (2135 and 1508, Geocodes 14 and 8, respectively). Locations can be identified by up to five geometry types; hence, figures 34 and 35 sum to a number greater than the total number of runway incursions in the database.

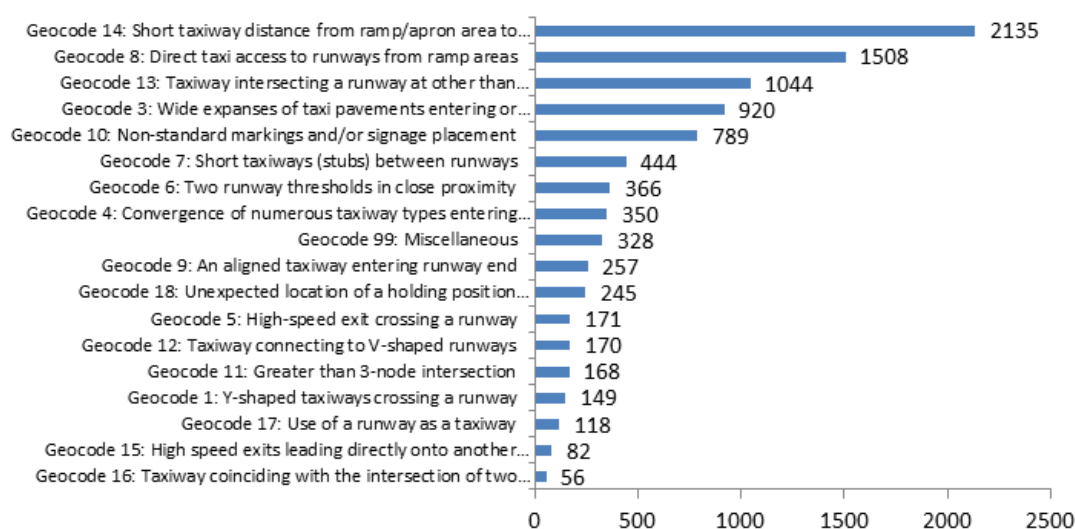


Figure 35. Runway Incursions Associated With Each Problematic Geometry Type for all Categories

To determine the relationship between the geocodes at a location to the number of PD and V/PD runway incursions occurring there, the incursion totals were divided by the number of locations exhibiting the geometric characteristics. Using this criterion, an unexpected location of a holding position marking on a parallel/entrance taxiway was associated with the highest rate of incidents (4.30 per location on average), as shown in figure 36.



Figure 36. Runway Incursion Rate of Each Geometry Type for all Categories

Figure 37 compares the geocode occurrences versus runway incursion rate. Similar to the analysis of all incursion types, despite being the most infrequently identified geometry types (identified at less than 1% of geometry locations), Geocode 18, representing locations with an unexpected location of a holding marking on a parallel or entrance taxiways, was associated with the highest rate of incursions (4.30 per location). In contrast, the data showed that although Geocode 14, representing short taxi distance from ramp/apron area to a runway, had the highest rate of occurrence at 58% of geometry locations, it had the third lowest runway incursion rate at 0.55 incursions per location, as shown in figure 38.

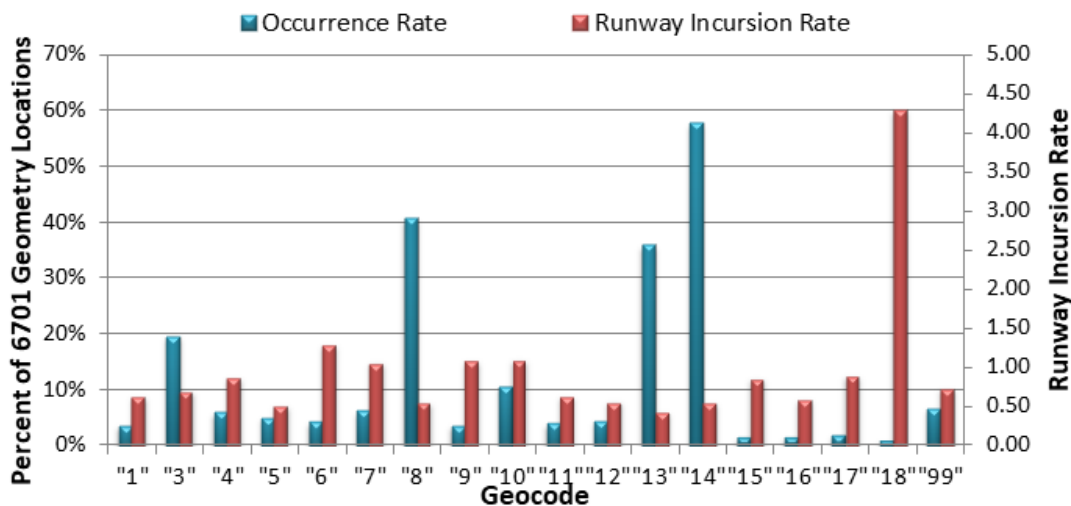


Figure 37. Geocode Occurrences Versus Runway Incursion Rate for all Categories

5.3.3 Runway Incursions—Categories 1A and 2A.

A filter was applied to examine the higher-incident areas where PD and V/PD runway incursions occurred. The locations listed as either 1A (66 existing hot spots) or 2A (53 other non-hot spot PTG locations) made up the 119 locations with the highest peak annual incident occurrence rates. The most common geocodes included the same two geocodes for the whole runway incursion analysis, Geocodes 14 and 8. The third most common geocode was wide expanses of taxi pavements entering or along a runway (Geocode 3), as shown in figure 38.

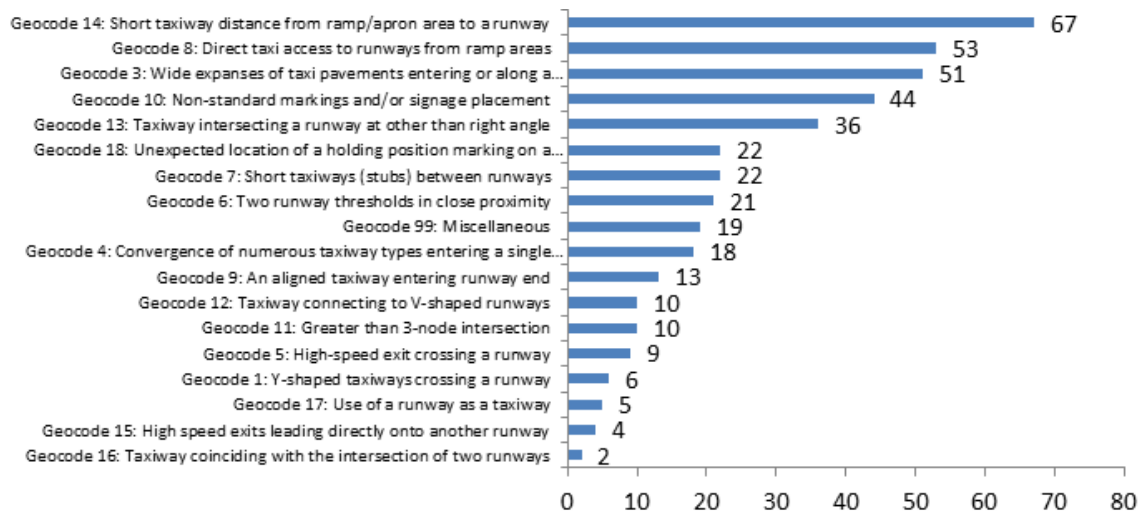


Figure 38. Geocode Occurrences at Inventoried Locations for Categories 1A and 2A

Figure 39 shows the total number of runway incursions for PTG locations categorized as 1A and 2A.

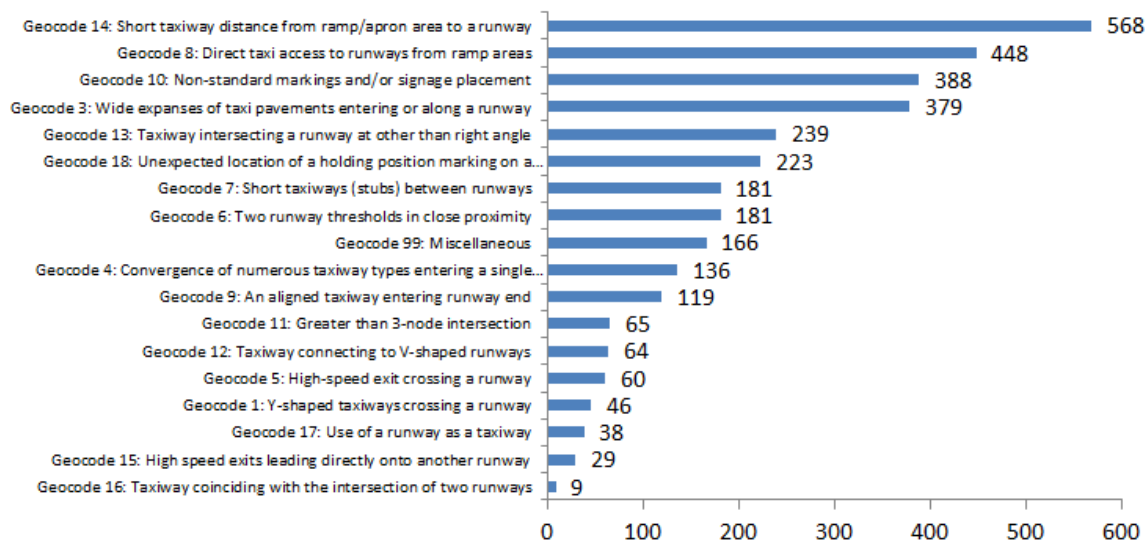


Figure 39. Runway Incursions Associated With Each Geocode for Categories 1A and 2A

Figures 40 and 41 show the relationship of the occurrence rate for the individual types of geocodes. Data indicated that the incident rates of geocodes at the 119 high-incident category locations differed from the overall runway incursion rates for all locations. As shown in figure 40, locations with unexpected holding position markings on a parallel/entrance taxiway, Geocode 18, had the highest incident rate (10.14 per location). The next highest incident rates were not much less: Geocode 9, aligned taxiways entering runway ends, was 9.15; and Geocode 10, nonstandard markings and/or signage placement, was 8.82. It should be noted that figure 40 is a ranking and does not indicate that the features with an associated low-incident rate are less important.

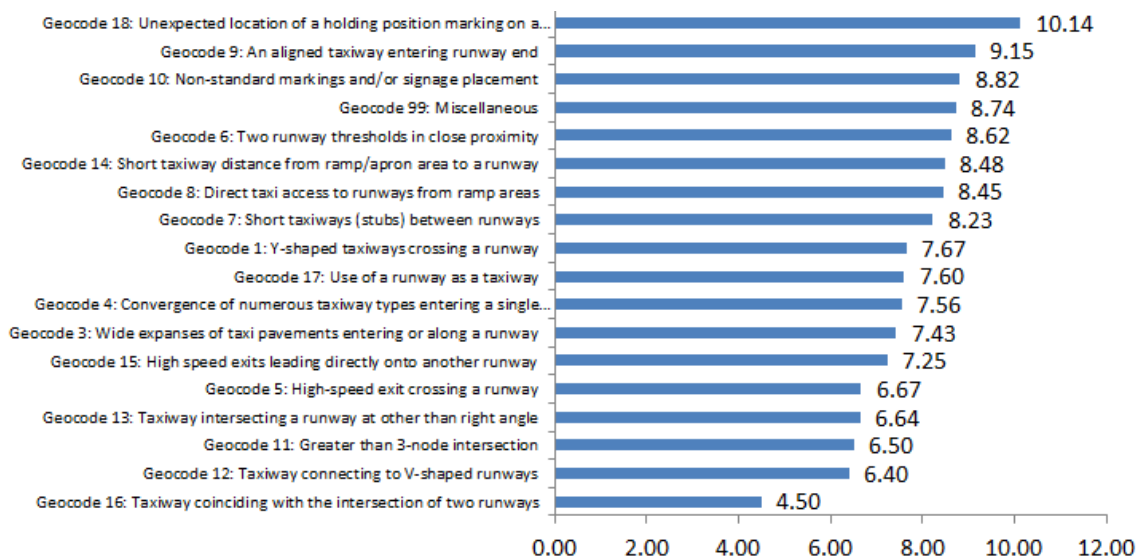


Figure 40. Runway Incursion Rate of Each Geometry Type for Categories 1A and 2A

Figure 41 compares the percentages of locations labelled with each geocode to the average number of incidents (rate) associated with the codes for high-incident locations (categorized as 1A and 2A). This figure shows that some geocodes with comparatively low occurrence rates can have higher incident rates than other geocodes with a much higher occurrence rate. For example, Geocode 9 (a taxiway aligned with a runway end), was identified at only 11% of 1A and 2A locations, but 119 runway incursions were associated with this geometry type. This resulted in an average runway incursion rate of 9.15 incursions per occurrence. Geocode 14 by contrast (short taxiway distance from ramp/apron to a runway entrance), which had more runway incursions in absolute terms (568), has a lower overall average of 8.48 per occurrence since many occurrences did not result in runway incursions. Therefore, geocodes with higher runway incursion rates are more severe with respect to the probability of a runway incursion.

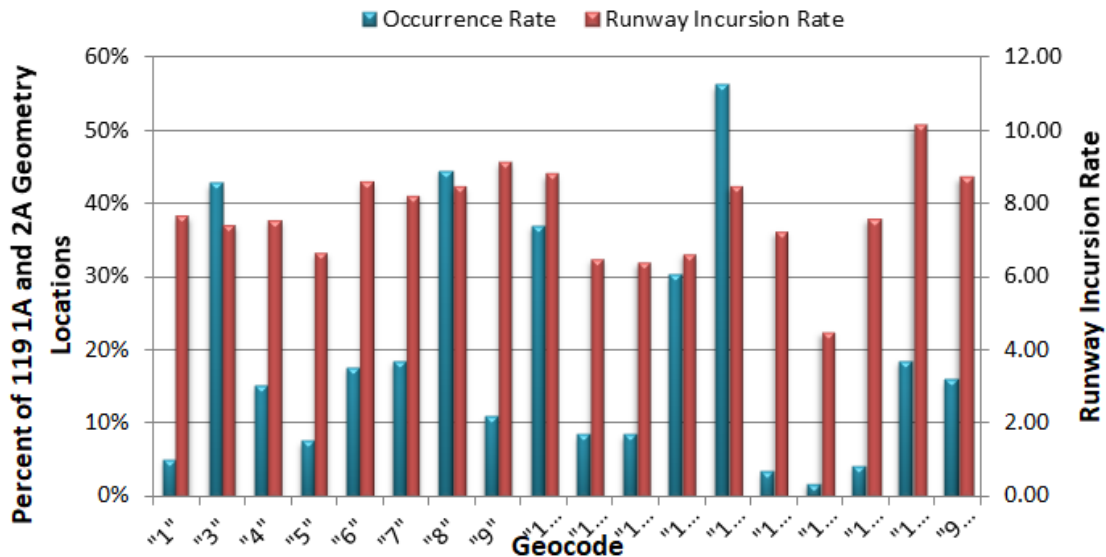


Figure 41. Geocode Occurrences Versus Runway Incursion Rate for Categories 1A and 2A

6. COST-ESTIMATING TOOL.

A cost-estimating tool was developed for the FAA and its respective Airport Regional and Airport District Offices to prepare preliminary program costs for redesign and/or construction for taxiways. This tool is an interactive Microsoft Excel spreadsheet that can be used to identify alternative solutions for eliminating PTGs and the rough order-of-magnitude cost associated with each.

The cost-estimating tool included the various intersection geometries between taxiways and runways based on the following inputs:

- Airplane Design Group (ADG)
- Taxiway Design Group (TDG)
- Taxiway Type
- Airport Elevation
- Approach Type

These taxiway intersection attributes, and the FAA design standards associated with each, contributed to the final design solution for a given PTG area.

Four taxiway types were considered for the general purpose of the cost-estimating tool.

- 90° Entrance—A standard 90° entrance taxiway is located on runway ends near the runway threshold. The taxiway centerline is perpendicular to the runway centerline. It is used for aircraft movement in one direction onto and off the runway.

- 90° Connector—A standard 90° connector taxiway is located at various places on the runway. The taxiway centerline is perpendicular to the runway centerline. It is used for aircraft movement in both directions onto and off the runway and often across the runway.
- High-Speed Exit—A standard 30° high-speed taxiway is located at various places on the runway. The taxiway centerline is at a 30° angle to the runway centerline. It is used by landing aircraft to maintain a higher rate of speed exiting the runway and continuing in one direction onto a parallel taxiway.
- High-Speed With Backturn—A standard 30° high-speed taxiway is located at various places on the runway. The taxiway centerline is at a 30° angle to the runway centerline. It is used by landing aircraft to maintain a higher rate of speed coming off the runway and continuing in two directions onto a parallel taxiway.

User inputs (e.g., airport location, pavement type, area of possible pavement removal) provide a predetermined base cost per square foot that is applied to the estimated project dimensions. The total program cost is the arithmetic result of the construction cost and the program fees (general consulting engineering fee, construction management and inspection fee, and the environmental analysis allowance). The final program cost is a preliminary program-level cost for constructing and/or fixing problematic taxiways.

7. CONCLUSIONS.

The inventory of all pilot deviation (PD) and vehicle or pedestrian deviation (V/PD) runway incursions at National Plan of Integrated Airport Systems-towered airports reported from October 1, 2007 (when the current definition of runway incursions was adopted) to September 30, 2013, indicated certain locations where runway incursions clustered. Incident categories assigned to the 6701 locations with geocodes will assist the Federal Aviation Administration (FAA) in determining a location with high incidents, in order to study the geometry at that location.

Preliminary analysis, based on the frequency of the type of problematic geometry, shows that the most frequently occurring problematic geometries were (1) short taxiway distance from ramp/apron area to a runway, (2) direct taxi access to runways from ramp areas, and (3) taxiways intersecting a runway at other than a right angle.

To determine the relationship between the type of problematic geometry at a location and the number of PD and V/PD runway incursions occurring there, the incursion totals were divided by the frequency of the geometry types. Geocode 18 (unexpected location of a holding position marking on a parallel/entrance taxiway) was the most prone to runway incursions with, on average, four runway incursions occurring at locations where this type of geometry exists. For the highest incident category (i.e., 119 locations listed as either Category 1A (66 existing hot spots) or Category 2A (53 other non-hot spot PTG locations)), the most common geometry types were (1) short taxiway distance from ramp/apron area to a runway, (2) direct taxi access to runways from ramp areas, and (3) wide expanses of pavement entering a runway.

Incident rate analysis at Category 1A and 2A locations showed that Geocode 18 was associated with the highest rate of incidents, followed by (1) taxiways aligned with runway ends, and (2) nonstandard signage or marking placement. The incident rate was also compared to the rate of occurrence for each geocode. By conducting this comparison, some problematic geometry types, such as Geocode 18 and Geocode 9 (taxiways aligning with runway ends), have greater incident rates than other geometry types, despite those geocodes occurring relatively infrequently in the database. Therefore, this database can facilitate the prioritization of locations based on the geometry type incident rates.

The combination of analysis and tools included in the PTG inventory and the cost-estimating spreadsheet have assisted the FAA in identifying high-incident PTG areas and assign a program cost to rectify each location. As part of the multi-year improvement program to correct high-incident locations on airport taxiways, the information contained in the Geographic Information System database and the approximate program cost provided by the cost-estimating tool will aide fund allocation and planning.

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