Classification of Runway Configurations for Capacity Analysis of Airports Serving Small Aircraft

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Abstract— In this paper we describe the development and application of GIS-based algorithms to automate and standardize the process of classifying runway configurations for United States' airports primarily serving small aircraft. Runway configurations are detected using data sources from the National Flight Data Center (NFDC). Identified runway configurations are then categorized by a defined classification schema through geocoding algorithms using geoinformatics software. The automated classification of thousands of such runway geometries will serve as an important input to developing capacity models specific to these smaller airports.

Keywords-component; Small aircraft; runway configuration; runway classification (key words)

I. INTRODUCTION

In this paper we propose a methodology to automate the process of identifying and categorizing runway configurations for United States' airports primarily serving small aircraft. This work was motivated by the Federal Aviation Administration's Office of Airports' program to support advances in estimating operational capacity of these vital components to the nation's air transportation system. The methodology proposed leverages the Federal Aviation Administration's National Flight Data Center (NFDC) datasets, and geo-informatics algorithms developed on QGIS and ArcGIS software platforms. In doing so, multiple types of runway configurations from single runway environments to multiple runways arranged in various configurations are categorized.

Operations of small aircraft are a vital, yet often overlooked, component of the total volume of air traffic. Airports serving small aircraft often find that this portion of their overall aircraft operations is significant, and maybe the driver of airport capacity. Small aircraft are defined as those weighing less than 12,500 lbs., such as single and twin piston engine propeller driven aircraft. These aircraft are primarily used for unscheduled air services for passengers and freight activities, flight training, or recreational flying. Airports that serve these aircraft perform a diverse role in the national aviation system.

Airports serving small aircraft are primarily found at small hub, non-hub, and general aviation airports, as categorized by the FAA's National Plan of Integrated Airport Systems (NPIAS) [1]. These categories are based on the number of commercial enplaned passengers, types of based aircraft, operational characteristics, and geographic factors. The FAA concluded that the categories of airports serving small aircraft suggest effective funding allocation for investment plans [2].

The desire for further understanding the operational capacity of airports serving smaller aircraft is the motivation for this study. While the FAA has focused its capacity modeling efforts on airports primarily serving large commercial aircraft, understanding that small airports, those that primarily accommodate smaller aircraft, also have capacity concerns. The wide variety of aircraft using these facilities, along with the wide variety of runway configurations of these smaller airports, create unique challenges to estimating operational capacity. Prior studies have concluded that the number and configfuration of an airport's runways is essential to assess the capacity of an airport [3] .

The FAA has recently developed new models to determine the capacity of airports as described in the FAA / National Academies' Airports Cooperative Research Program (ACRP) Report 79 [4]. These models require data inputs which include the configuration of a given airport's runway environment. Understanding that there may be lots of variations on how to describe the geometry of an airfield's runways, the FAA desires to have a comprehensive data set that describes, using a standard methodology, the runway configuration of the nation's 19,000+ airfields, including more than 3,000 airports that it funds under the Airport Improvement Program. To manually go through these thousands of airports and determine a runway configuration arbitrarily would be burdensome and create inconsistencies in the data set. The goal of this research is to automate the process of identifying, evaluating, and categorizing runway configurations for all airports. The completed dataset will be an important input into the new FAA airport capacity models, particularly for those serving smaller aircraft.

II. INVENTORY

Creating an inventory of the runway configurations requires the data cleaning process to extract the airports with each runway. We use three datasets and to integrate the datasets using the references from the International Air Transportation Association (IATA) airport codes: 1) the National Plan of Integrated Airport System (NPIAS) data, 2) NFDC airport facility data, and 3) NFDC runways data. The data cleaning process is represented in Figure 1.

According to the categories in NPIAS, we obtain the list of airports categorized as either small-hub, non-hub, or non-primary / general aviation airports as a proxy for those serving small aircraft, which is 3,024 based on NPIAS 2019-2023. Note: it is understood that there are thousands of additional airports in the United States that are not included in the NPIAS, that may primarily accommodate small aircraft operations. With this understanding, this study focuses on NPIAS airports, and notes our classiifciation methodology as applicable to all airports environments.

The National Flight Data Center (NFDC) affiliated with the FAA is the institution to collect US aviation datasets with quality control and publication of the data on a 56-day update cycle. NFDC publishes four datasets: 1) airport facility data, 2) airport runways data, 3) airport remarks data, and 4) airport schedule data. First, airport facility data mainly includes physical parameters and operations such as geolocational information of facility and the number of operations by the type of services: commercial services, commuter, air taxi, GA local, GA itinerant, and military. Second, runway data provides runway characteristics and geolocational information like longitude and latitude of physical runways. Third, airport remarks data includes information on the remark element name. Last, airport schedule data provides information about airport attendance schedule. This study employs the airport runways dataset. From this data, this study acquires the geolocational information (latitude and longitude) of each runway end for all airports.

NFDC airport facility data includes a series of characteristics of the different types of air facilities. The data has 19,619 facilities, including airports, seaplane bases, heliports, balloon ports, glide ports, and ultralight ports. Since our analysis applies to the airports, we filtered out the data by the types of the facility, to 13,061 airport facilities.

NFDC runways data includes a total of 23,421 runways for all types of air facilities such as the NFDC airport facility data. Unfortunately, NFDC runways data did not include information on the facility types to each runway, so we refer to runway IDs to exclude the runways of seaplane bases, heliports, and other air facilities. According to the selection process, 7,306 runways include geolocation information of the runway ends.

The organized datasets are integrated through the two steps. First, we join two NFDC datasets - airport facility data and runways data - using the site number that represents the unique identifier of individual airports. The joined data finds 7,226 runways, which involves the runways of all airports across the US. Thus, to choose the runways solely for airports serving small aircraft, we merge the selected runways with the list of airports from NPIAS. As a result, we find a total of 2,960 airports with 4,494 runways, which excluded 64 of airports that have no geolocation information of runways. These 2,960 airports are used in this study to detect runway configurations.

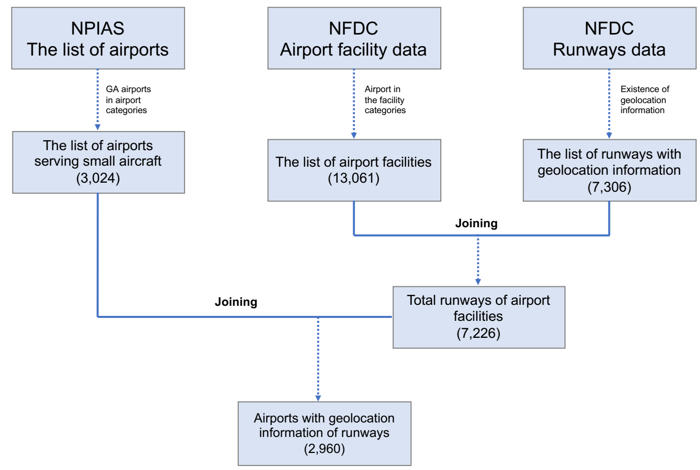

Figure I Data Cleaning Processes

III. Runway Configuration Detection Methods

A. Procedure

We follow multiple steps to identify the runway configurations because the types of configurations are determined by the number of runways. The procedure to detect the configurations followed:

- *Finding single-runway airports and multiple runways GA airports.*
- *Selecting multiple runways airports.*
- *Classifying multiple runways airports into the number of runways: two-runways, three-runways, and over three-runways.*
- *Detecting runway configurations for two-runways airports from the three types of runway configurations: Parallel, intersecting, and open V.*
- *Detecting runway configurations for three-runway airports from the five types of runway configurations: Three parallel, two parallel with one intersecting, two parallel with open V, three intersecting, and three open V.*

As the first process of identifying runway configurations, we calculate the number of runways at each of the 2,960 of airports from NFDC database. Table 1 shows the number of airports by the runway counts. According to table 1, we find that most airports are shown as single-runway airports; 1,670 of airports fall into the single runway category. Furthermore, we observe that only a few airports have more than three-runways, 29 airports have four runways, and 3 of airports have five runways. As a result of the summary of runway counts, we targeted the airports with multiple runways to detect runway configurations from the developed automatic method using geoinformatics software.

TABLE 1: RUNWAY COUNTS SUMMARY

Single runway	Two runways	Three runways	Four runways	Five runways
1,670	1,080	180	29	3

B. Geocoding Methods

The procedure of detecting runway configurations is conducted by two geoinformatics software products: QGIS 3 and ArcGIS 10.3. QGIS 3 is used for automatic geocoding longitude and latitude of the ends of each runway. Geodetic information of runway ends found in the NFDC runways dataset are formatted by the DMS forms (degrees, minutes, seconds), but ArcGIS can only geocode decimal degree format. Since ArcGIS cannot generate the geocoded coordination of each runway end, we use the alternative geoinformatics software that can geocode DMS form, QGIS 3. With the use of QGIS 3, we geocode each base end and reciprocal end of each runway. Then, the geocoded points draw a line between runway ends and the results are exported as a shapefile consisted of polygons.

C. Dual runway configurations

Airfields found to have two runways are considered to be in a "dual runway" configuration. This study considers three geometries for the dual runway configuration, parallel runways, intersecting runways, and open-V runways, as illustrated in Fig. 2. This study further classifies parallel runways by their geographic separation between runway centerlines, as illustrated in Table 2. These configurations are recognized in FAA Advisory Circulars (ACs) 150/5060-05 and 150/5300-13 as determinants of airfield capacity [5], [6].

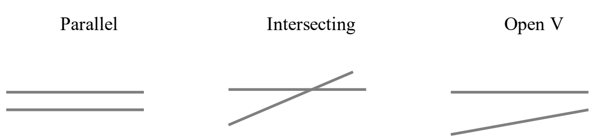

Figure 2 Three types of Two Runway Configurations

TABLE 2: PARALLEL RUNWAY SEPARATION REQUIREMENTS

Separation	Term	Use
0 - 700 ft.	No Separation	May not be used simulatneously. Only one operation on one runway at a time.
700 - 2500 Ft.	Close Separation	Only simulatneous VFR operations allowed, only one runway use in IFR.
2500 - 4300 ft.	Medium Separation	VFR simultaneous operations allows. IFR: One runway may be used for IFR departures simultaneous with the other accomodating arrivals
> 4300 ft.	Far Separation	Dual parallel operations allowed in VFR and IFR conditions

The first step in the detection method is to assign variables to the latitude and longitude of each end point in the runway dataset. Examples of assignment is illustrated in Fig. 3.

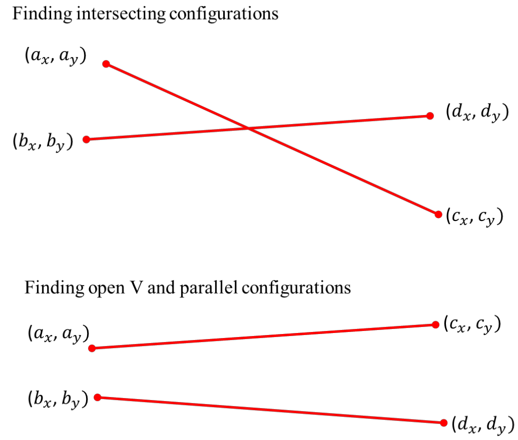

Figure 3 Example identification of runway end points.

where variables a and c are end points of one runway, b and d are end points of the second runway, and subscripts x and y represent the latitude and longitidue of each point, respectively.

We first apply these variables to determine whether or not the two runways intersect, using equation (1) below:

$$\boldsymbol{a} + t(\boldsymbol{c} - \boldsymbol{a}) = \boldsymbol{b} + s(\boldsymbol{d} - \boldsymbol{b}) \qquad (1)$$

If t, s are both between 0 and 1, then the intersection of the lines is contained within the segments, meaning that these are indeed intersecting runways. These parameters can be solved using vector analysis as illustrated by equation (2):

$$\begin{bmatrix} \mathrm{t} \\ \mathrm{s} \end{bmatrix} = [\mathbf{c} - \mathbf{a} \quad \mathbf{b} - \mathbf{d}]^{-1}[\mathbf{b} - \mathbf{a}] \qquad (2)$$

If it is determined that the two runways do not intersect, we then compute the angle between two runways to determine either a parallel or open-V configuration. The angle between the two runways is measured by the coordinates of each runway end. We compute the angle of each runway using the function of arctan2(y, x). The equation is specified as:

$$\alpha_0 = arctan2(c_y - a_{y,} c_x - a_x)$$
$$\alpha_1 = arctan2(d_y - b_{y,} d_x - b_x) \qquad (3)$$

Then, we calculate the difference between the angles from the equation stated above, specified in equation (4) as:

$$\alpha_0 - \alpha_1 = P \qquad (4)$$

If the value of P is from -6 to +6 degrees, we define the configuration as the parallel type. If the value of P is over either +6 or -6 degrees, we define the configuration as the open V type.

D. Example dual-runway configuration analysis

Following the two steps of the detection methods, we find the runway configuration of the two example airports: Fort Lauderdale Executive Airport (FXE) and Phoenix Deer Valley Airport (DVT), which have two runways. First, we calculate the value of t and s for FXE and DVT to check whether the runways have an intersecting point, which is measured from Equation (1). Table 3 represents the results of FXE and DVT. We find that FXE has the values of t and s that are in the range for the intersecting configuration. In contrast, DVT shows that the values are -37.03 and 19.42 for t and s, which indicate that the runways have not the intersecting point. According to the result, DVT needs one additional step to determine its runway configurations. Using Equation (2), we measure the angles between two runways. α_0 shows the value of -3.04 and α_1 is the value of -2.51. Then, we calculate the difference, which is demonstrated by the value of *P*. We find that *P* shows -5.55, which is within the range of the parallel runway type. As a result, we detect that DVT has a parallel configuration from our methods.

TABLE 3: RUNWAY COUNTS SUMMARY

Value	FXE	DVT
t	0.41	-37.03
s	-0.97	19.42

E. Determining triple runway configurations

Airfields with three runways have more complexity than dual runways configurations. Figure 4 shows seven types of three runway configurations determined by all possible combinations from each three runway. Using the equation (1), (2), and (3), which composed the dection processes of three types of dual runway configurations, we will make new algorithms of each type of the configuration to develop an automated method of configuration detection.

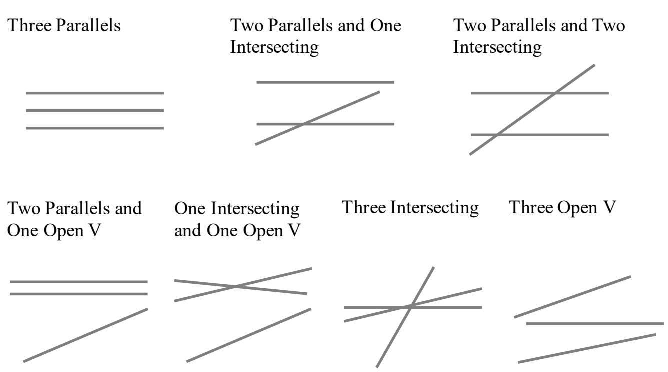

Figure 4 Seven Types of Three Runway Configurations

IV. CONCLUSION

This study develops algorithms that determine runway configurations of small airports in the US. We validate that our methods detect different types of runway configurations using the two example airports – FXE and DVT, to determine whether the runways were parallel or intersecting configurations.

In forthcoming research, we will conduct three analyses. First, we will add to the dual-runway analysis by automating the method to evaluate the separation of parallel runways. Second, we will create the method to categorize triple runway configurations, followed by configurations of quadruple runways. Third, we will develop an R package on the detection of runway configurations and upload an R package at Comprehensive R Archive Network (CRAN), which would be easily downloaded and applied by potential users who want to figure the runway configuration of an airport.

The results of this work have been promising and have the great potential of providing a standardized runway configuration dataset needed as part of our larger effort to contribute to developing enhanced models to estimate the capacity of airports serving primarily small aircraft.

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